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COMMAND AND CONTROL FOR DISTRIBUTED OPERATIONS: AN ANALYSIS OF POSSIBLE TECHNOLOGIES, STRUCTURE AND EMPLOYMENT

by

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In order for information to move efficiently in asymmetric combat environments the military has had to flatten its organization and find ways to network those decision makers who impact the ebb and flow of events on the ground day to day. This thesis further develops the concept of Marine Corps distributed operations (DO) under the current Marine Air Ground Task Force (MAGTF) structure. Analysis will focus on the integration of traditional RF nets into a networked based architecture using emerging Commercial off the Shelf (COTS) Radio Frequency to Internet-Protocol (RF to IP) technologies that would further advance the Marine Corps' MAGTF capabilities.

Evaluations include traditional Marine Corps ground radio assets along with COTS equipment. Tests include laboratory and field settings. Key performance measures include interoperability, bandwidth measurements, range and power consumption. Additional measures include interoperability with current internet protocol networks and methods of execution.

Findings support the bridging of military tactical ground radios into IP networks or into other IP enabled communication devices. Radio interoperability is investigated over various network mediums such as IEEE 802.16, IEEE 802.11A and Mesh links.

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Findings demonstrate gateway of military tactical ground radios into IP networks or into other IP enabled communication devices are feasible. Radio interoperability is investigated over various network medium such as IEEE 802.16, IEEE 802.11A and Mesh links.

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ACRONYMS AND ABBREVIATIONS

AES	Advanced Encryption Standard
AO	Area of Operations
AODV	Add-hoc On-demand Distance Vector
AP	Access Point
ARP	Address Resolution Protocol
C2CE	Command and Control Compact Edition
C2PC	Command and Control Personal Computer
C4	Command, Control, Communications and Computers
CAS	Close Air Support
COP	Common Operational Picture
COMSEC	Communications Security
CONOPS	Concept of Operations
COTS	Commercial Off The Shelf
DARPA	Defense Advanced Research Projects Agency
DAMA	Demand Assigned Multiple Access
DC	Direct Current
DDACT	Dismounted Data Automated Communications Terminal
DISN	Defense Information Systems Network
DO	Distributed Operations
DoD	Department of Defense
DSR	Dynamic Source Routing
EPLRS	Enhanced Position Location Reporting System
FBCB2	Force Battle Control, Brigade and Below
FSSG	Fleet Service Support Group
FDD	Frequency Division Duplex
GIG	Global Information Grid
GIGA	Lab Global Information Grid Applications and Operations Code Laboratory
GPS	Global Positioning System
HF	High Frequency
HMMWV	High Mobility Multi-Wheeled Vehicle
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
ITV	Internally Transportable Vehicles
JTR	Joint Tactical Radio
JTRS	Joint Tactical Radio System

Kbps	Kilobits per second
LAN	Local Area Network
LOE	Limited Objective Experiment
LOS	Line of Sight
LFOC	Landing Force Operations Center
LPI/LPD	Low Probability of Intercept/Low Probability of Detection
LRV	Light Reconnaissance Vehicle
MAC	Media Access Control
MAGTF	Marine Air-Ground Task Force
MANET	Mobile Ad-hoc Network
MEF	Marine Expeditionary Force
Mbps	Megabits per second
MCTSSA	Marine Corps Tactical Systems Support Activity
MCWL	Marine Corps Warfighting Lab
MDACT	Mounted Data Automated Communications Terminal
MEA	Mesh Enabled Architecture
MMR	Micro-Mesh Router
MSC	Main Support Component
NCW	Network Centric Warfare
NIPRNET	Nonclassified Internet Protocol Network
NLOS	Non-Line of Sight
NSA	National Security Agency
NPS	Naval Postgraduate School
OEF	Operation Enduring Freedom
OFDM	Orthogonal Frequency Division Multiplexing
OIF	Operation Iraqi Freedom
OLSR	Optimized Link State Routing
OSI	Open Systems Interconnect
OTM	On-the-Move
PCMCIA	Personal Computer Memory Card International Association
PDA	Personal Data Assistant
PKI	Public Key Infrastructure
PLI	Position Location Information
PtMP	Point-to-Multipoint
PtP	Point-to-Point
QAM	Quadrature Amplitude Modulation
QDMA	Quadrature Division Multiplex Access
QOS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RF-to-IP	Radio Frequency into Internet Protocol

RO	Radio Operator
SA	Situational Awareness
SCR	Single-Channel Radio
SPAWAR	Space and Naval Warfare Center
SINCGARS	Single-Channel Ground and Airborne Radio System
SIPRNET	Secure Internet Protocol Router Network
SNMP	Simple Network Management Protocol
SS	Subscriber Station
STAN	Surveillance, Targeting and Acquisition Network
STEP	Strategic Tactical Entry Point
STS	Soldier Tactical Software
TSAT	Transformational Satellite
TACSAT	Tactical Satellite
TDD	Time Division Duplex
T/E	Table of Equipment
T/O	Table of Organization
THHR	Tactical Handheld Radio
TOC	Tactical Operations Center
TSC	Tactical Satellite Center
TNT	Tactical Network Topology
UHF	Ultra High Frequency
USSOCOM	United States Special Operations Command
VAP	Virtual Access Point
VHF	Very High Frequency
VOIP	Voice over Internet Protocol
VTC	Video Teleconference
WIMAX	Worldwide Interoperability for Microwave Access

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I. INTRODUCTION

A. BACKGROUND

Today our armed services are engaged in the Global War on Terrorism where the enemy is adaptive, dispersed and organized to exploit our weaknesses. The unconventional means our adversaries use require the United States to employ all of its resources and leverage its technological superiority to combat this deadly enemy. The wars in Iraq and Afghanistan have changed how we command and control our forces. Information on the battlefield can be the determining factor of who wins or loses these conflicts. Determining who receives the right information and when is key when fighting an unconventional foe that is constantly looking for gaps or weaknesses to exploit to his advantage.

Change is nothing new to the military. Each conflict in our nation's history has driven tremendous technological change. "The Information Age" is making distance less relevant. Information, and the decisions that result, can travel almost instantaneously to the place(s) where they are needed, making the location of those who gather, analyze, make decisions and possibly those who act on these decisions largely irrelevant."[1] The military is constantly looking for ways to deliver critical information to the decision maker charged with operational and tactical objectives. In order for information to move efficiently in asymmetric combat environments the military has had to find ways to network those decision makers who impact the ebb and flow of events on the ground day to day. By

[1] Alberts, Garstka, Stein. *Network Centric Warfare*: *Developing and Leveraging Information Superiority,* Washington D.C.: CCRP Publication Series, February 2000.

enabling the warfighter to receive and send more information they can better adapt to the complex battlefield environment.

Currently our military is looking for new ways to help the warfighter become more lethal by equipping him with tools to improve the decision making process and thereby moving faster than an enemy can react. These tools however bring another layer of complexity to the fight. Each new technology brings with it an outlay of more money, more time and more training for those intended to be helped by them. For the military, sometimes technology moves faster than what can be realistically fielded. Legacy systems that have proven effective in the past must be used in new and creative ways. In order to bridge the gap between old and new, the military must take an adaptive approach to end systems and while exploiting new technologies.

On April 25,th 2005, General Michael W. Hagee, 33rd Commandant of the Marine Corps, introduced a new concept called Distributed Operations (DO). Since this time a large effort has been made by the Marine Corps to make this concept a reality. A renewed focus on Marine Corps small unit leaders (platoon and lower) has forced the Marine Corps to take a hard look at its current command and control systems and look for realistic ways to make the DO concept a reality.

During Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF), the Marine Corps' maneuver warfare philosophy was solidified with maximum decentralization of decision-making guided by commander's intent. The concept of Distributed Operations (DO) is the deliberate use of separation and coordinated, interdependent, tactical

actions enabled by increased access to functional support, as well as enhanced combat capabilities at the small-unit level.

Small units such as, infantry companies and platoons are no longer expected to only conduct traditional military operations but more dynamic missions that execute in a disaggregated fashion dispersed beyond the normal range of mutually supporting organic direct fires, but linked through a command and control network (C2). The intent of DO is not to replace traditional capabilities but rather enhance them to help shape battlespace.

The Marine Corps is in the process of developing the DO concept into future warfighting capabilities that still focus on the Marine Corps’ core competencies of maneuver warfare. Marine Corps Warfighting Lab (MCWL) is currently conducting Limited Objective Experiments (LOE) that put to test current capabilities and develop future requirements for DO.

This research focuses on equipping the DO platoon with improved C2 assets. This thesis addresses the communication concerns of the experimental platoon conducting distributed operations training and reveals the shortcomings of the current command and control architecture. It identifies the concept of operations and how communications become an enabling or limiting factor. Research efforts address new technologies intended to leverage current command and control systems a DO platoon currently possess. Additional research also addresses network architectures and new commercial-off-the-shelf (COTS) devices that may realistically allow the warfighter to have the information he requires.

This project is a continuation of ongoing research that began in June 2006. The NPS Distributed Operations Working Group began studying this concept and began a series of laboratory and field experiments intended to solve many of the command and control challenges faced by DO. A collaborative effort by another disparate research group with similar research goals was established to help consolidate resources and intellectual expertise.

B. OBJECTIVES

The primary objective of this research is to demonstrate how the current and future DO communications architecture can be leveraged into an IP (Internet Protocol) network environment. The research investigates the use of Twisted Pair WAVE™ server technology to bridge legacy RF (Radio Frequency) communications equipment into a tactical internet in order to determine the capabilities and limitations it provides a DO force and supporting units.

C. RESEARCH QUESTIONS

1. Can current legacy radios being proposed by MCWL for DO platoons be used on a routable IP tactical network? How specifically does a current VHF/UHF radio used by operating forces link to an IP network infrastructure? What significant capability does this provide?

2. Can IEEE 802.16 wireless backbone network architectures be extended to traditional legacy radio equipment? For example, can a commander of a DO unit make a digital phone call from a VoIP (Voice over Internet Protocol) type phone to a legacy VHF/UHF radio? What

capability does this provide a Marine infantry battalion operating in dispersed operating environment where units are separated 50-100km?

3. What are the security considerations with regards to RF – IP?

D. SCOPE

The scope of this thesis will include:

- An analysis of the current and proposed DO command and control architectures.
- A review of MCWL's Limited Objective Experiment 2 (LOE2) and the communication challenges it reveals. Additionally analysis of on site survey results as administered in May of 2006 to the DO experimental platoon.
- A review of RF to IP (Radio Frequency to Internet Protocol) COTS equipment and how it can leverage current legacy radio assets into an IP network environment.
- Field experimentation to test USMC radio equipment and its interoperability with COTS RF-to-IP technology.

E. METHODOLOGY

1. Research USMC Distributed Operations publications, articles and related material.

2. Conduct Marine Corps Warfighting Lab (MCWL) site visits. Interview key personnel and conduct limited survey to identify areas of concern regarding the command and control of a distributed operations unit.

3. Research RF to IP technologies, related reference material and industry experts. Additionally read relevant and recent NPS thesis research related to command and control systems and Distributed Operations.

4. Perform laboratory and field tests to determine key performance measures.

F. ORGANIZATION OF THESIS

CHAPTER I. This chapter discusses the problem and provides background information on the command and control challenges posed by Distributed Operations. The problem addresses the reason for conducting this research, and provides a framework in which the reader can have context.

CHAPTER II. This chapter further defines the concept of Distributed Operations and identifies its command and control challenges. This chapter also highlights the current and proposed communication architecture for Distributed Operations. Here MCWL site visit observations are discussed and analyzed.

CHAPTER III. This chapter discusses what laboratory and field experiments where conducted as well as the results obtained. This chapter provides an in-depth analysis of RF-to-IP technology and how it integrates into the current and proposed DO command and control architecture. Additionally, a detailed review of the COTS technology used in this thesis is examined and researched.

CHAPTER IV. This chapter discusses the external supporting factors affecting Distributed Operations. It identifies command and control issues and how a Marine Corps would integrate RF-to-IP technology into its current

command and control architecture. It also addresses how this technology can be used throughout the tactical network.

CHAPTER V. This chapter provides a conclusion for the research study as well as articulates areas that warrant further analysis through future research.

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II. DISTRIBUTED OPERATIONS CONCEPT OF OPERATIONS

A. OVERVIEW

Distributed Operations describes an evolving concept that seeks to maximize the MAGTF commander's ability to employ tactical units across the depth and breadth of a nonlinear battlespace, in order to achieve favorable intelligence-driven engagements as part of the Joint Force Commander's overall campaign. A robust and easily accessible C4 backbone and prompt, responsive joint fires enable this capability.

Distributed operations constitute an additive capability.[2] In simple terms, this means that DO will do nothing to degrade the time-honored core competency of Marine infantry to "locate, close with, and destroy" our Nation's enemies, wherever they may find them. "As dictated by current or anticipated national strategy and tactical situation, the MAGTF's fully netted DO capable forces will alternately disperse or mass to best exploit any opportunity our adversaries offer."[3]

Understanding the concept of Distributed Operations is important. Equally important is to understand what Distributed Operations is not. A Marine DO platoon is not a special operations or reconnaissance unit. Although those entities may perform distributed operations in

[2] The term "additive capability" is a term used to describe the Marine Corps Maneuver Warfare doctrine and builds upon the unique competencies and the extensive capabilities that Marines already provide to the Joint warfighting community.

[3] Marine Corps Warfighting Lab. "Questions and Answers about Distributed Operations." Internet: http://www.mcwl.usmc.mil/SV/DO%20FAQs%2016%20Mar%2005.pdf, March 20, 2005 [October 9, 2006].

conjunction with their mission, Marine DO units will not give up their conventional capabilities must have while conducting DO. It is merely an additive capability which requires additional training and skill development to small unit leaders.

B. TABLE OF ORGANIZATION/TABLE OF EQUIPMENT

1. Organization: The experimental Distributed Operations (DO) capable platoon is based on a standard Marine Corps Infantry Rifle Platoon of 1 officer, 42 enlisted Marines, and the standard attachment of 1 Corpsman. The rank and basic T/O weapons distribution generally remain the same; some crew served weapons are added to the organic structure. The task organization of the platoon for DO is outlined below in Figure 1:

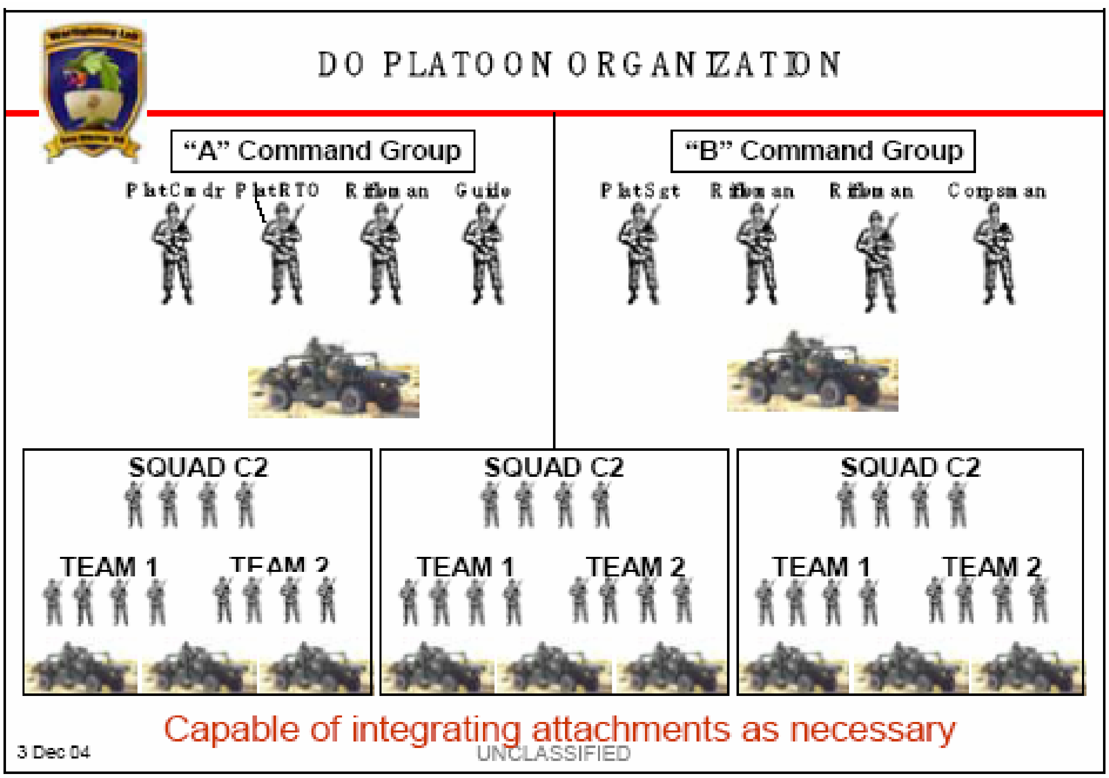

Figure 1. Organization of DO Platoon. (From: [4])

2. Communications Equipment: For the purpose of this research, equipment other than communications will not be discussed. Current infantry rifle platoons operate with only one VHF radio by Table of Equipment (T/E) allowance. Squads traditionally do not have radios. DO capable platoons are equipped with a significant communications suite. Table 1 describes the type of communications equipment currently used by DO.

	Nomenclature	Waveform	Range	Role
	Personal Role Radio (PRR)	UHF	500 - 1000 meters	Intra-Team Communications
	PRC 148	VHF / UHF	VHF: 4-7 mi UHF- LOS	Platoon - Squad - Team C2 CAS Control
	Expeditionary Tactical Communications System (ETCS)	Netted Satellite Communications (Low earth orbit)	Worldwide	Squad - HHQ Plat - HHQ Fires Request **PLI (OTH/OTM)**
	PRC 117	VHF / UHF / Satellite Communications	VHF:7-10 mi UHF: LOS Sat: WW	Squad - Plat - HHQ CAS/Fires Control **(OTH - Digital)**
	PRC 150	HF / HF Digital	30+ miles	Plat - HHQ **(OTH)** Logistics

Table 1. Communications Equipment and Capabilities (From: [4])

The DO capable platoon will be able to talk over-the-horizon (around the world) via standard TACSAT communications and the Expeditionary Tactical Communications System (ETCS). In addition, the squad will have the organic capability to communicate in VHF and UHF, and the platoon will also have an HF capability.

Because of this additional amount of communications equipment, a DO platoon has an enormous capacity to communicate over great distances even within the platoon. Figure 2 describes how the communications equipment is dispersed within the command elements of the platoon. Figure 3 describes the squad outlay.

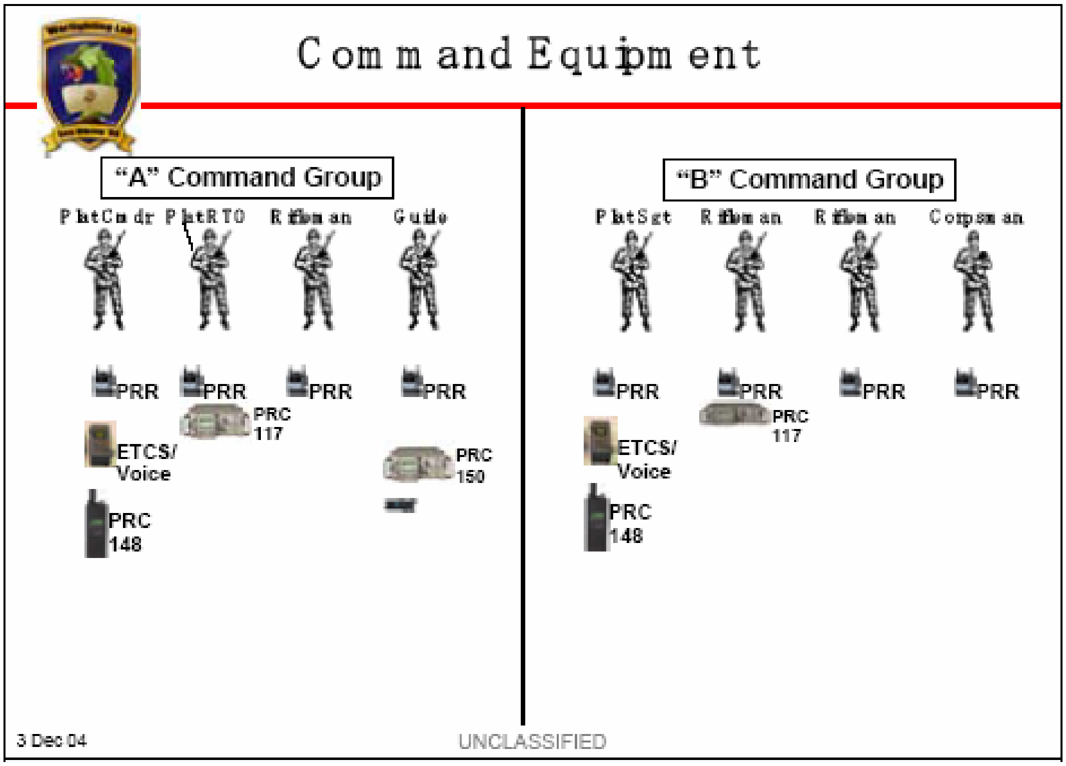

Figure 2. Communication Equipment for DO Command Element. (From: [4])

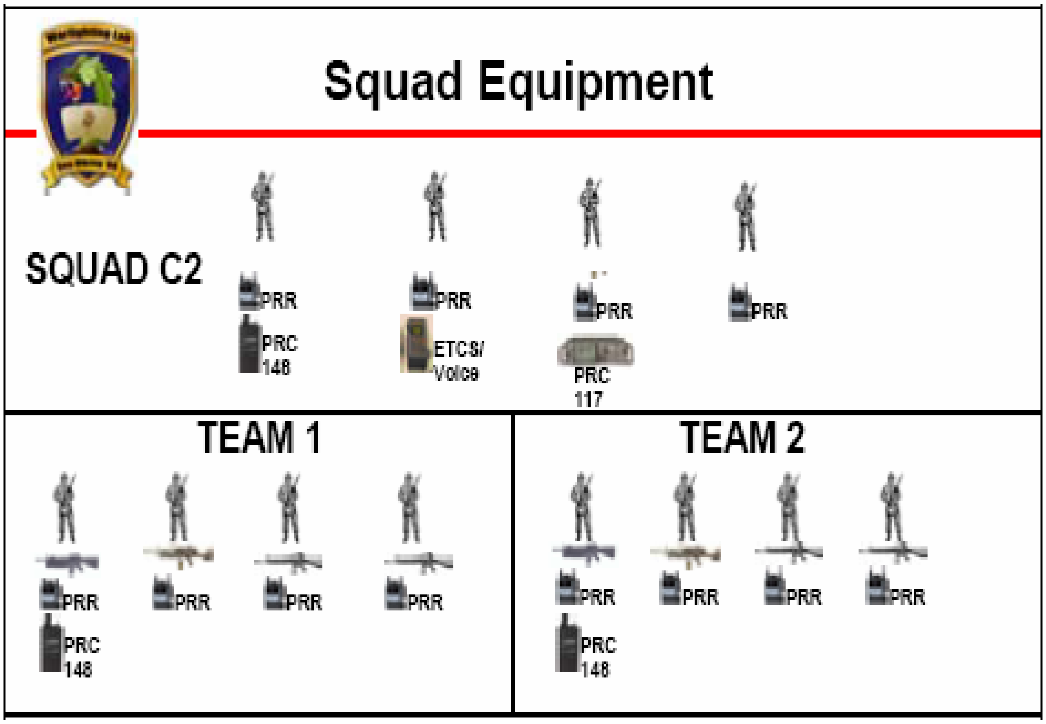

Figure 3. Communication Equipment for Squad Element. (From: [4])

C. LEGACY SYSTEMS OVERVIEW

1. AN/PRC-117F Multi-band, Multi-mission Man-pack Radio

The PRC-117F (See Figure 4) is an emerging radio system within the Marine Corps. It was initially fielded to support ground-air operations. Since the beginning of the campaigns in Iraq and Afghanistan, these radios have increasing become popular among conventional units. DO calls for each individual squad to operate the PRC-117F. The radio’s multiband capability enables the squad to use satellite communications. A breakdown of the PRC-117F capabilities is listed below.

Figure 4. AN/PRC-117F. (From: [13])

- Covers entire 30 to 512 MHz frequency range while offering embedded COMSEC, SATCOM, and ECCM capabilities.
- Secure interoperability with SINCGARS (MIL-STD 188-220)
- Can be configured for man-pack, vehicular and base station applications suitable for operation in a multimode service environment.
- Comparable in size to the AN/PRC-119
- Interoperable with legacy encryption systems and acts as a translator between otherwise incompatible radios. The hardware can be reconfigured and software reprogrammed to optimize performance and add capabilities without opening the radio.

- Capable of transmitting in VHF single channel, VHF frequency-hopping, Ultra High Frequency (UHF), and in tactical satellite Tactical Satellite (TACSAT) modes.[4]

2. AN/PRC-119F Single Channel Ground Air Radio System (SINCGARS)

The PRC-119F (See Figure 5) is the primary radio used by Marine Corps ground units today. It is interoperable with several SINCGARS variants and is the primary radio used by ground forces in Iraq and Afghanistan. Of note, this radio doesn’t possess any IP networking capabilities. It was designed primarily for voice traffic but can facilitate some data communications on a very limited scale. Radio characteristics are listed below.

Figure 5. AN/PRC 119F (From: [10])

- 30-88 MHz VHF-FM
- 2320 Channels
- Single channel and Frequency Hopping (FH)

[4] Note: Using TACSAT in the dedicated mode, with a channel dedicated to use of one element with a simple uplink and downlink, is much easier than using TACSAT in the Demand Assigned Multiple Access (DAMA) mode. DAMA requires more programming and every entry must be correct or communications on the satellite will be denied by the controlling authority.

- 6 FH presets (including TRANSEC keys)
- 6 Single channel presets plus manual and cue channels
- Enhanced data mode (BPS)1200, 2400, 4800, 9600
- Standard data mode (BPS) 600, 1200, 2400, 4800,16,000
- Power Output 4.5 watts nominal
- Less than 8 pounds with embedded battery
- 33-hr. battery life (6:3:1 duty cycle with BA-5590 battery)
- Jam-resistant communications
- Primary Power +13V <1.5A
- Standard Batteries BA-5590, BB-390 (rechargeable)

3. AN/PRC-148 Multiband Inter/Intra Team Radio (MBITR)

The PRC-148 (See Figure 6) is a multiband radio (VHF/UHF) used primarily for squad to platoon communications. This radio system enables a DO squad to conduct Close Air Support (CAS) missions as required. This radio has many of the same capabilities as the PRC-117F. The main difference is its weight and power output. It’s intended for command and control within the platoon and is used extensively throughout the Marine Corps. A more detailed list of its capabilities is listed below Figure 6.

Figure 6. AN/PRC-148 (MBITR) (From: [11])

- 30 to 512 MHz Frequency Coverage
- 5 and 6.25 kHz Step Size
- Rapid Start-up Time
- Less than 30.6 ounces
- AM/FM
- Voice/Data
- HAVEQUICK I/II, SINCGARS ESIP Single Channel and Frequency Hopping, ANDVT
- Selectable RF Output Power (0.1 to 5 watts)
- Analog Narrowband Capable (12.5 kHz)
- 2 and 20 Meter Immersible Variants
- AM and FM Synchronous Data Rates of 12 and 16 kbps

- AM and FM Asynchronous Data Rates below 4800 baud
- Retransmission Between Handheld Radios (with special purpose filters and cable)
- Joint Interoperability Test Center (JITC) Tested
- Encryption - NSA Endorsed Type I & Type III DES

4. AN/PRC 150C High Frequency Radio

The PRC-150C (Figure 7) resembles the PRC-117F and has many of the same program features. However this system is primarily HF it is capable of extending its range up to 60 MHz. It is intended for over the horizon (OTM) long-range ground communications. This system does have limited ability to pass digital communications but is not used for this purpose within the DO construct.

Figure 7. AN/PRC-150C HF RADIO (From: [13])

- Frequency Range 1.6 to 59.999 MHz
- Net Presets 75, fully programmable
- Emission Modes J3E (single sideband, upper or lower, suppressed carrier telephony)
- Power Input 26 VDC (21.5 to 32 VDC)

- Radio Weight 10 lb (4.7 kg) without batteries
- Encrypted Data HF: MIL-STD-188-110B App. C (9600bps and 12,800 bps uncoded),
- NSA-certified U.S. Type 1 encryption.
- Automatic Link Establishment (ALE) provides faster and more reliable linking and increased data link throughput, even in degraded channel conditions.
- Advanced frequency hopping (ECCM) allows secure communications in the presence of jamming.

5. Personal Role Radio (PRR)

The PRR radio (Figure 8) is intended to connect all DO platoon members within relative close proximity of each other. There is no Type 1 encryption available for this system but the system relies on Direct Sequence Spread Spectrum (DSSS) frequency modulation and low power for Low Probability of Detection/Low Probability of Intercept (LPD/LPI). Of note, the radio can be configured (dual mode) to work with the other tactical radios so that a user can switch from inter-team to inter-squad communications. Additionally the wireless Push-to-Talk (PTT) allows users to key the radio without moving their hand from their weapon system. The main purpose for this radio is inter-team communication.

Figure 8. PERSONAL ROLE RADIO (PRR) (From: [14])

- 50mW transmit power using Direct Sequence Spread Spectrum modulation at 2.4GHz
- Typical operating range is 500m in open terrain, and through 3 floors of a building or through 5 houses in Urban environments
- Wireless Press to Talk with up to 2m range
- 256 channels, 16 available directly to the user.
- Operates from 2 x AA batteries for greater than 24 hours (1:7:16 Tx/Rx/Standby)
- Operates independently of any infrastructure
- NBC Compatible

6. EXPEDITIONARY TACTICAL COMMUNICATIONS SYSTEM (ETCS)

ETCS (Figure 9) provides voice and data communications either over-the-horizon (OTH) or on-the-move (OTM). The system is a modified version of the Low Earth Orbit (LEO) Iridium satellite system that provides netted (one to many) push-to-talk communications. The handset is a modified Motorola 9505 handset with an integrated GPS and Group Radio Controller to manage the

voice/data traffic and individual nets. For DO it is mainly used for a Universal Fires Net where by all fire-capable entities can communicate directly with the platoon. The system experiences a short delay due to the nature of delay in satellite communications.

Figure 9. ETCS (From: [15])

The ETCS system does experience unexpected outages.[5] This may create problems for users trying to call and adjust for supporting arms. Outages can occur at any time thus making the system unpredictable. ETCS does provide some good utility despite its unpredictability. Its Position Location Indicator (PLI) function provides SA for entities that have the system connected to C2PC. A basic configuration is depicted in Figure 10. Another problem is capacity. The system has a limited amount of

[5] Comments regarding ETCS performance were obtained from MCWL LOE-2.

channels and is seen as a short-term solution by MCWL until either the technology is matured or improved.

Figure 10. ETCS Configuration (From: [15])

D. COMMUNICATION CAPABILITIES

1. Current Architecture

The primary architecture is voice communications. ETCS does provide Position Location Information (PLI) but requires a second set of those systems to use. Additionally ETCS does have limited capacity and is a short term solution for the platoon. ETCS is discussed in greater detail above. Figure 11 describes the voice network for a DO capable platoon and how it communicates within the Marine Corps Air Ground Task Force (MAGTF).

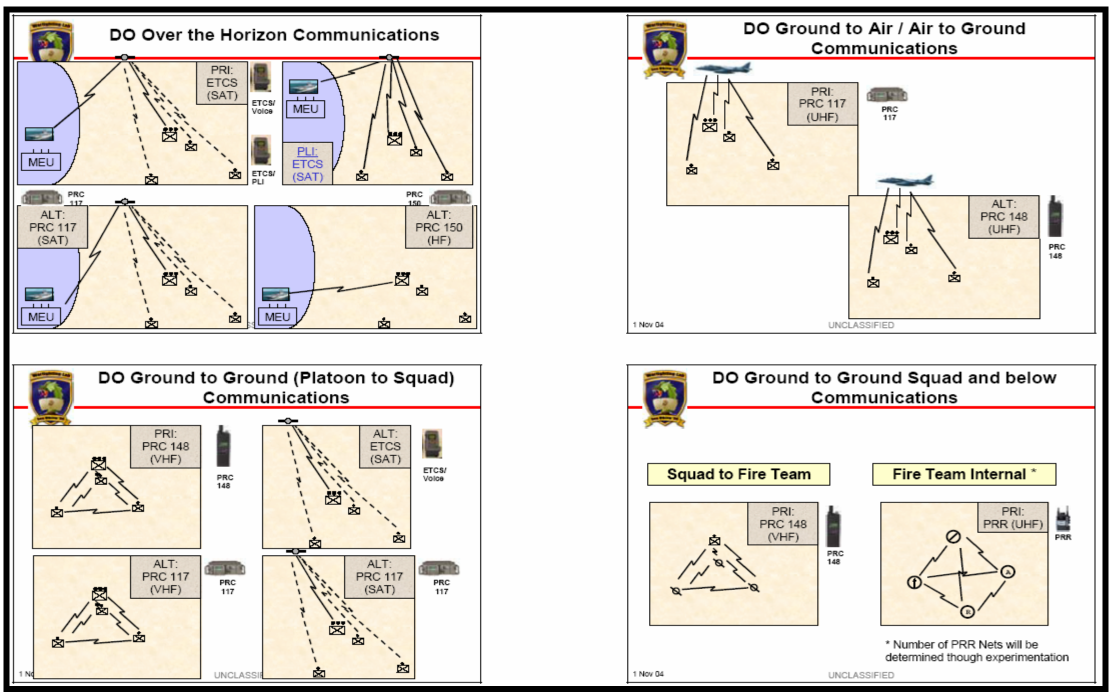

Figure 11. DO Platoon Voice Network (From: [4])

The current architecture represents the current radio technologies available within the Marine Corps. Of note there is no digital communications present. Nor is there any significant way to bridge other communication assets with those fielded.

2. Proposed Architecture:

The Marine Corps Warfighting Lab provided guidance to the NPS DO Working Group on their vision for DO. It followed closely to current programs of record and listed possible devices that could be used by a DO platoon. Figure 12 illustrates the DO communication architecture.

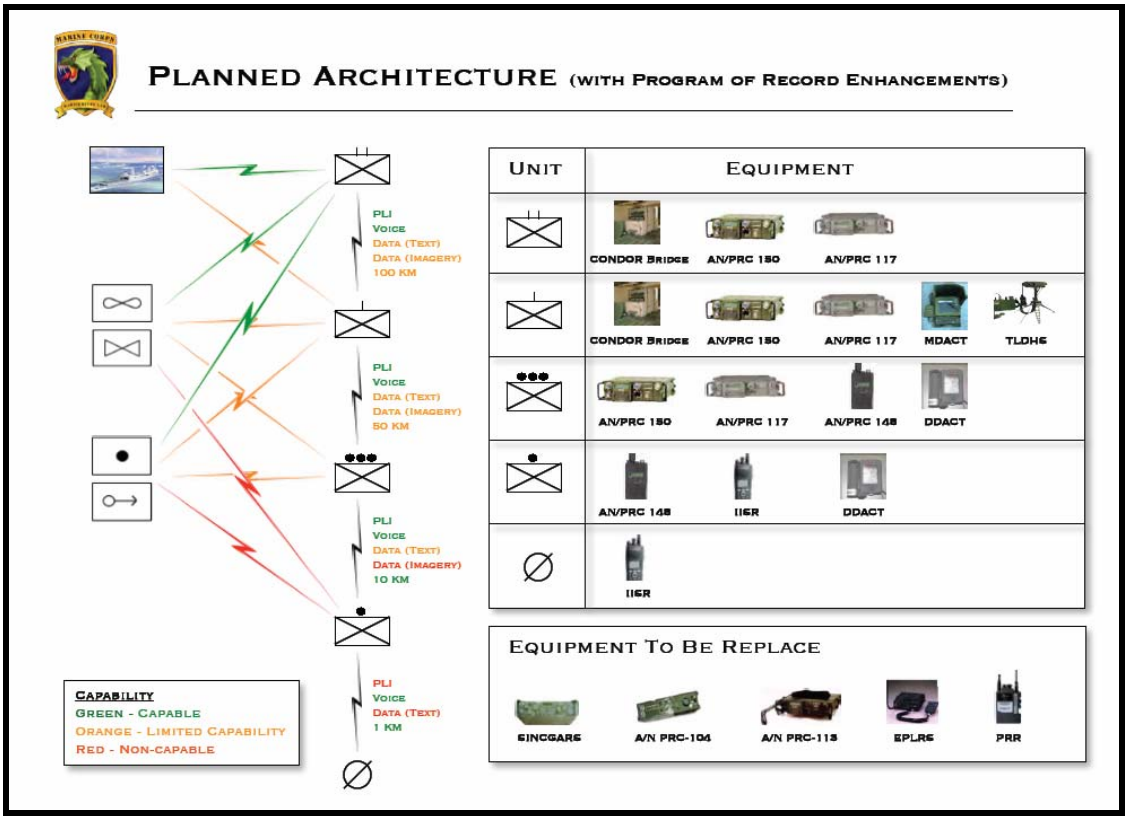

Figure 12. DO Proposed Architecture (From: [5])

MCWL’s DO concept does plan for increased mobility with the use of High Mobility Multi-Wheeled Vehicles (HMMWV) or Internally Transportable Vehicles (ITV) which could impact the use and type of communication equipment used. However it was made clear by MCWL that mounted operations are but one of type of operation and any solution should not be vehicle-centric.

E. COMMUNICATION SHORTFALLS

The additional communications equipment afforded a DO capable platoon is quite impressive. Rather than having one or two radio assets the platoon is equipped with many more. Each Squad and Fireteam leader possesses the ability to communicate equally internally or externally as required. However merely giving more radios to more Marines is only one way to improve information sharing. The current architecture does not bring any other significant information source into play.

Asymmetric warfare demands information superiority. Distributed Operations demands small unit leaders make tough decisions guided by commander’s intent, with the ability to disperse or aggregate as the mission requires. DO units must have shared awareness of the battlespace. This requires bringing critical information to those who can make the largest impact. The authors believe this can be accomplished in a two prong approach. First create and maintain a network that can harness and focus vital information to those who need it. Then bring those who need the information into an established network and provide a path where information can flow at crucial times. Possibly a combination of both are the answer.

For Distributed Operations this means providing reliable, secure communications so foot-mobile infantry can carry equipment and power sources within their standard load, yet link to any joint element.

Information vetted as intelligence must be freely available and constant. A voice network as depicted in Figure 12 only provides for one communication solution. MCWL does expand this by providing a netted low earth orbit

satellite communication-enabled system called ETCS, which delivers point to multipoint voice and PLI to a DO force. MCWL understands this system is a short term solution and is discussed in detail below.

The current DO platoon communications architecture provides little to no ability to send and receive data files, text messages, imagery, or video feeds outside the tactical command and control hierarchy. For example, an element that has important information to share must funnel this information through the established organizational command structure. Time sensitive items may not be disseminated appropriately, thus losing the tactical edge over the enemy. The current architecture does not support any other network devices, which could assist distributed operations units. Disparate radio frequency (RF) centric voice networks and associated end systems are not always capable of connecting to larger tactical networks.

There appears to be little attempt to bridge legacy ground communication assets within an established data network. The main reason appears to be the distances involved in conducting distributed operations. Figure 12 indicates Distributed Operations could operate up to 10 - 100 kilometers away from other supporting or adjacent units. This presents several challenges. Logistics, joint fires and tactical support all hinge on reliable communications.

DO units are provided two satellite communications alternatives which provide long range reach-back communications. The PRC 117F and the ETCS are capable of providing this capability. In reality these satellite communication assets could prove problematic since

satellite channels and availability are limited for tactical units. The ETCS is not a fully fielded system therefore may be limited in scope and availability for a large architecture.

F. JOINT TACTICAL RADIO SYSTEM (JTRS)

Any discussion of communication shortfalls for DO would not be complete without investigating how the Department of Defense (DOD) has addressed military communications capabilities and shortfalls. An enormous amount of research and development has been poured into tackling this issue. This section examines why legacy radio systems will continue to be the mainstay for the Marine Corps in the near-term.

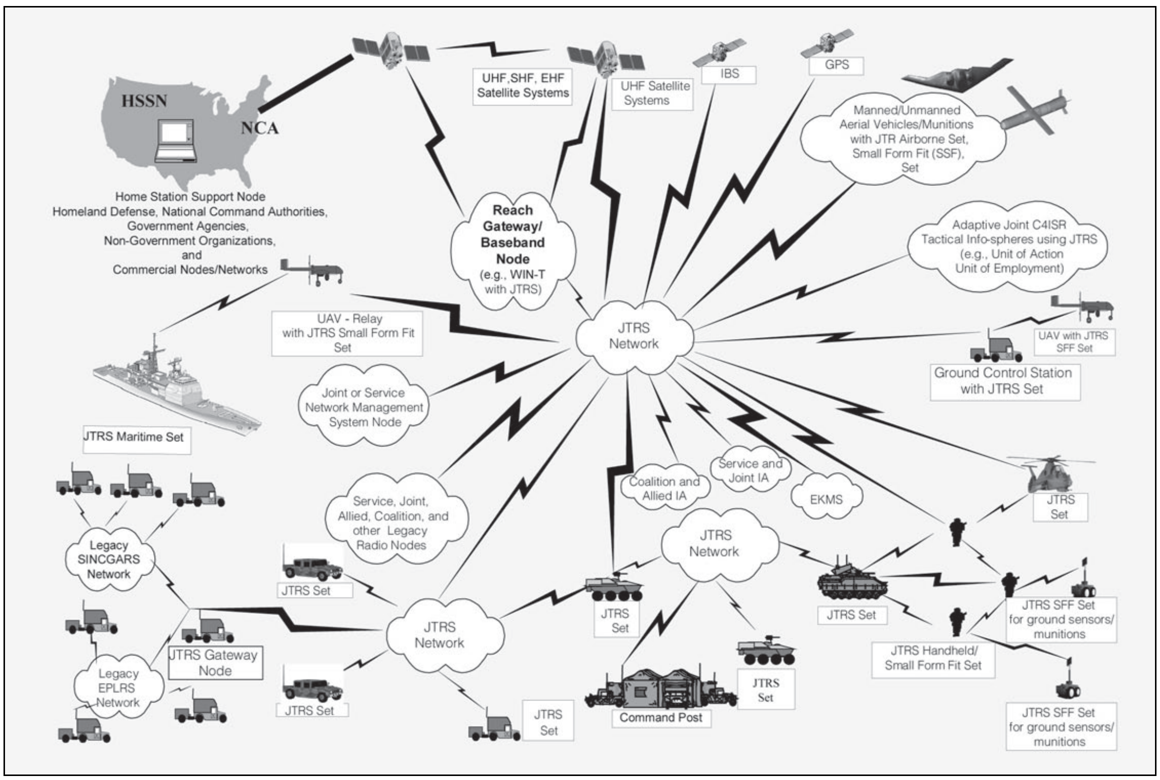

Figure 13. JTRS Operational Overview (From: [19])

Each service had tried to develop service specific versions of programmable, modular, multi-mode, multi-band radios without much success.[6]

Each service had experienced difficulty communicating other services in both Grenada and Desert Storm. They were plagued by interoperability problems and limited bandwidth which did not meet expanding communication requirements. JTRS is a consolidated attempt to solve these problems.

1. Mission Need

The DOD sought to develop software-programmable tactical radios that would provide video, voice, and communications, with interoperability across several platforms. Current radio systems lack interoperability and have insufficient bandwidth to meet present and future communications challenges. The goal is an all service radio with the ability to provide mobile networked-connectivity across the battlespace.

The question becomes, why is JTRS important? The transformational effort of DOD's architecture depends on the information infrastructure called the Global Information Grid (GIG). JTRS would extend the GIG to the least advantaged users and provide connectivity to those currently out of reach.

2. Operational Requirements

The JTR would enable military commanders the ability to command and control their forces more effectively by providing more services such as voice, video, and data. The goals established by the Defense Planning Guidance

[6] Joint Program Executive Office (JPEO) for Joint Tactical Radio System (JTRS) February 2006. PDF Document, JTRS Overview. Internet: http://enterprise.spawar.navy.mil/body.cfm?type=c&category=27&subcat=60 ,[February 1, 2007].

(1998–2003) and Joint Vision 2010 state that the, "JTR will perform in the most flexible manner and be designed as a family of advanced, reliable and dynamic communications platforms. As a result, the JTR will be software-reprogrammable, multi-band/multi-mode capable, networkable, and provide simultaneous voice, data, and video communications."[7] The ground force version JTRS will provides surface-to-surface and surface-to-air communications. Command posts would use this system for command and control operationally. The systems are intended to facilitate air missions, common operational picture (COP) and other sensor data. Figure 14 depicts possible prototypes of JTRS radio.

3. Technical Characteristics & Requirements

The performance requirements for the JTRS radio are extensive. The requirements were changed in 2005 to reflect mobile ad-hoc networking. Here are but a few of the major requirements for JTRS:

- The JTR architecture shall be capable of supporting secure and non-secure voice, video and data communications using multiple narrow-band and wideband waveforms.
- The JTR program shall provide an internal growth capability through an open systems architecture approach in compliance with the Joint Technical Architecture, and shall be modular, scaleable, and flexible in form factor.
- The JTR shall provide the operator with the ability to load and/or reconfigure modes/capabilities (via software) while in the operational environment.[8]

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[7] SPAWAR Website, Operational requirements for JTR, Internet: http://www.fas.org/man/dod-101/sys/land/docs/jtr23_mar.htm [February 1, 2007].

[8] Ibid.

Figure 14. Prototype JTRS Radio (From: [20])

- The JTR shall have the ability to be reconfigured (hardware changes/upgrades) in the operational environment. The JTR shall be capable of operating in a radio frequency spectrum from 2 MHz to 2 GHz. The JTR shall be capable of incorporating military and commercial satellite and terrestrial communications above 2 GHz.
- The JTR shall have the ability to retransmit/cross-band information between frequency bands/waveforms supported (threshold.
- The JTR shall be capable of operating on multiple full and/or half-duplex channels at the same time.[9]

The Joint Requirements Oversight Council provided guidance to the JTRS operational requirements refinement. The intent was to fill gaps in the requirements that were identified by the operational stakeholders. For example, amendments to the Operational Requirements Document determined certain JTRS sets must be able to interface with a new satellite system called the Mobile User Objective

[9] SPAWAR Website, Operational requirements for JTR, Internet: http://www.fas.org/man/dod-101/sys/land/docs/jtr23_mar.htm [February 1, 2007].

System (MUOS). Requirement changes like this have plagued the program and slowed development.

4. Acquisition Strategy

The JTRS program was restructured in 2005. “The program plans to develop capabilities in increments rather than attempt to field a complete capability all at once, which was the previous approach.”[10] The focus has shifted to networking capabilities using three new waveforms and interoperability with legacy radios. All changes keep in mind the DOD’s focus on network centric operations. The list below gives examples of requirements that have been reduced:

- *Reduced number of waveforms:* The number of waveforms to be delivered for the first increment has been reduced from 32 to 11.
- *Reduced number of radio variants:* The number of variants to be delivered for the first increment has been reduced from 26 to 13.
- *Reduced number of waveform combinations per radio variant:* The original intent of JTRS was that most waveforms would operate on most radio variants. However, DOD determined that porting 32 different waveforms onto 26 different variants would have been an immense and costly undertaking.[11]

Figure 15 demonstrates the impact of the restructuring. “This shift is reportedly expected to lower program risk from high to moderate, and to reduce development costs from $6 billion to about $4 billion.”[12]

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[10] GAO DEFENSE ACQUISITIONS Restructured JTRS Program Reduces Risk, but Significant Challenges Remain.

[11] Ibid.

[12] Ibid.

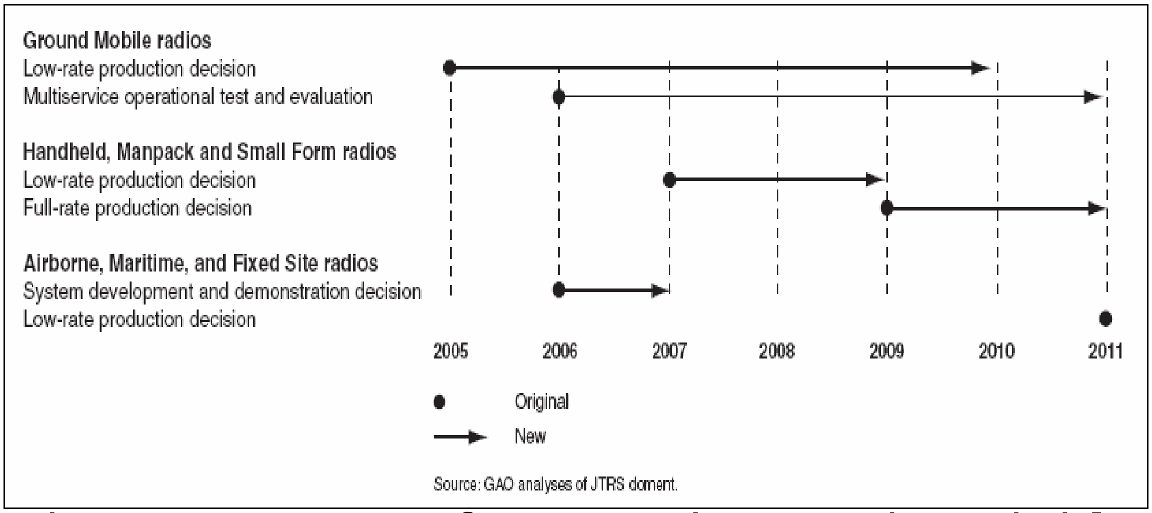

Figure 15. Impact of Restructuring on Product Schedules (From: [21])

5. Program Funding

Because of program setbacks and delays, the procurement of legacy radio systems has dramatically increased. "Since JTRS development will require at least several more years, it is likely that the estimated $11 billion investment in legacy radios will continue to grow."[13] Table 2 shows the annual procurement amounts for radio systems other than JTRS from 1998 through 2006.

Table 5: Estimated Procurement Amounts Required for Other Radio Systems from 1998 through 2006 by Procuring Organization

Dollars in millions

Year	Army	Air Force	Marine Corps	Navy	Combatant commands and agencies	Total
1998	0	$7.74	0	0	0	$7.74
1999	$91.55	$19.25	$1.30	$1.28	$24.87	$138.25
2000	220.89	65.68	25.63	63.74	0.60	376.54
2001	142.72	4.00	0	72.79	1.52	221.03
2002	54.02	1.62	2.38	60.56	71.17	189.75
2003	199.99	78.66	51.07	49.94	0.30	379.96
2004	668.18	104.10	42.58	326.32	3.29	1,144.47
2005	1,564.52	2,289.17	314.43	368.79	0.75	4,537.66
2006	a	a	a	a	a	4,170.00
Total	**$2,941.87**	**$2,570.22**	**$437.39**	**$943.42**	**$102.50**	**$11,165.40**

Source: GAO analysis of data provided by DOD.

[a] DOD provided only a total estimate for 2006.

Table 2. Procurement of Legacy Systems (From: [21])

[13] GAO DEFENSE ACQUISITIONS Restructured JTRS Program Reduces Risk, but Significant Challenges Remain.

Most of the current program cost has predictably been in R&D. Table 3 below shows the cost. The unit cost has yet to be determined.

Program Performance (fiscal year 2006 dollars in millions)

	As of NA	Latest 06/2005	Percent change
Research and development cost	NA	$1,027.7	NA
Procurement cost	NA	$1,649.1	NA
Total program cost	NA	$2,730.5	NA
Program unit cost	NA	TBD	NA
Total quantities	NA	3,338	NA
Acquisition cycle time (months)	NA	NA	NA

Costs and quantities reflect the program of record. Both are expected to change as a part of a program restructuring currently underway.

Table 3. JTRS Program Cost as of 2006 (From: [21])

6. Program Issues & Challenges

There are several challenges ahead for the JTRS program. The program still faces management and technical challenges that must be overcome. Long-term commitments from stakeholders and service components have been lacking. Although the program has been restructured, certain assumptions about Wideband Networking Waveform have not been solidified. However, “the program underestimated the complexity of meeting the Wideband Networking Waveform requirements and the services’ needs within the size, weight, and power constraints of the various user platforms.”[14] As of the date of this thesis, JTRS still has not come out of the prototype phase.

[14] GAO DEFENSE ACQUISITIONS Restructured JTRS Program Reduces Risk, but Significant Challenges Remain.

7. Moving Ahead Without JTRS

The Marine Corps is not waiting for JTRS to arrive. Several efforts are being made to increase the amount of bandwidth to tactical units deployed to Iraq. The employment of commercial Support Wide Area Network (SWANS) (See Figure 16) has made dramatic increases in tactical data networking possible.

Figure 16. SWAN Terminal (From: 23)

There are several iterations of the Support Wide Area Network employed in theater. Currently there are VSWAN (Video) and LSWAN (Logistic) systems in Iraq with plans to provide 20 more (Ground) versions to Forward Operating Bases (FOB) and Mobile Training Teams (MTT).

System description:

- The major functional groups of the package are Ku-Band Very Small Aperture Terminal (VSAT) antenna, modem, routers, accelerators, KG-175/TACLANE, and Cisco Call Manager for SIPRNET Voice over Internet Protocol (Secure VoIP). NIPRNET VoIP ready.
- All equipment is packaged in transit cases which are all HMMWV transportable.
- The Ku VSAT terminal is an auto-acquiring antenna.

- The modems are ViaSat Linkway IP, allowing hub and spoke or mesh architectures.
- DISN services are accessed through the existing MNF-I tactical network.[15]

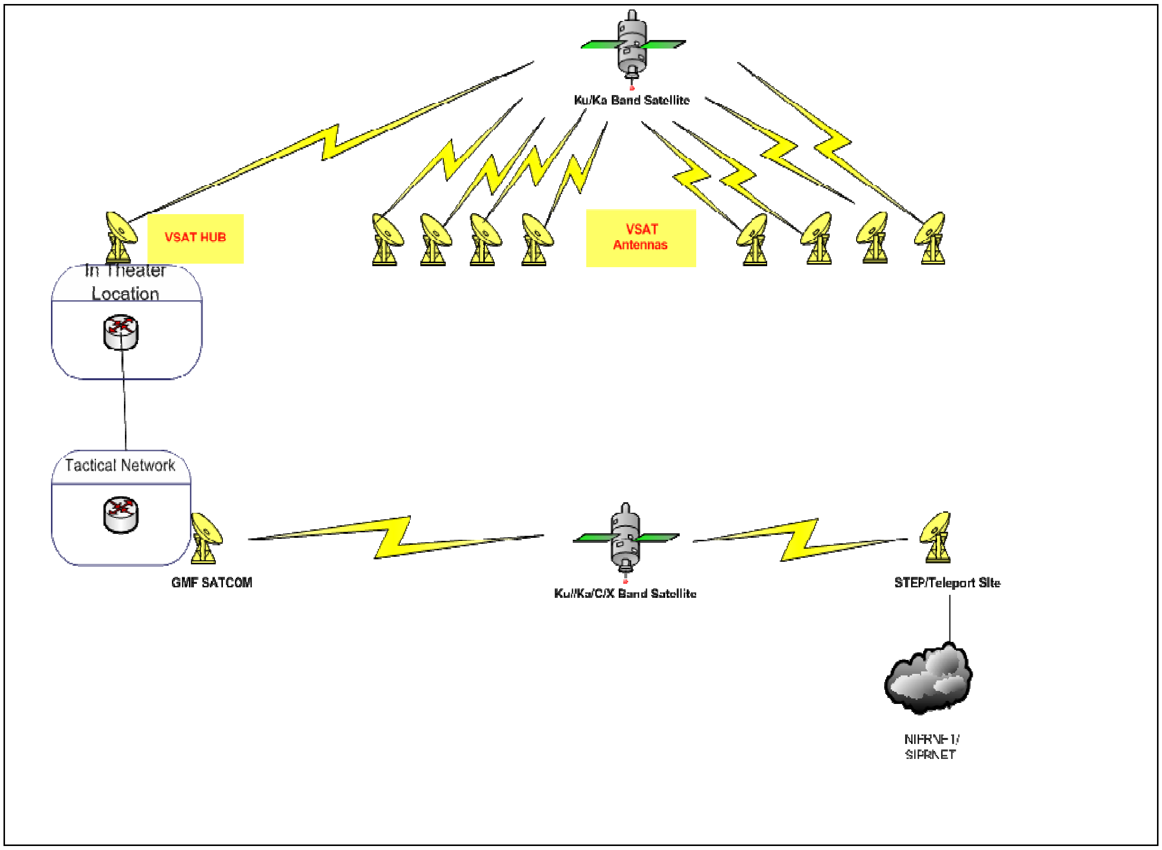

Figure 17. SWAN Architecture View (From:[22])

These systems provide commercial Ku band TDMA access and provide 32 MHz of bandwidth up to 25 Mbps to each terminal. The same contractor (DATA PATH Corporation) is currently working with the U.S. Army. Additionally the Marine Corps has employed terrestrial communications links to further extend access to digital communications. Accompanying each SWAN are two Wireless Point-to-Point Link (WPPL) IEEE 802.16 radios which provide up to 49Mbps of bandwidth.

[15] Chris Cox,and David Joseforsky. GSWAN Brief. July 2006.

The authors believe this trend in Iraq will continue in the future. Thus the trend of providing an increased networking capability to disadvantaged users on the battlefield will continue. This capacity only previously afforded to higher echelons is currently reaching further down the organization. Doctrine has not caught up with reality on the ground. In chapter IV of this research the authors discuss how the communications T/E and its limited bandwidth at lower levels affect DO.

8. Conclusion

U.S. military forces lack interoperability and the capacity our information requirements demand. It is clear the JTRS program has struggled from its inception. What is also clear is for distributed operations to work in the near-term, the Marine Corps can not wait for the JTRS solution. Legacy systems will continue to be purchased and maintained until a suitable replacement becomes available. Until then, DO units must leverage what resources they now possess with emerging technologies.

Due to the enormity of the JTRS program and the complexity of the system; it is unclear if even a new JTRS radio would even properly support DO units. The Marine Corps' DO concept does not specify a JTRS capability. However, it does pursue many of the same attributes the JTRS program is attempting to solve. The JTRS program does not have a requirement to support DO type missions but the assumption could be made that a more interoperable, increased capability, inter-service radio would help in this endeavor. The detailed architecture in which JTRS would operate in is not thoroughly well thought-out. DO units not only require new communication systems to support

their mission but an architecture that is adaptive to changing conditions on the battlefield. It is the opinion of the authors simply giving a DO unit another new communication device with more capability is not the answer.

G. MCWL 29 PALMS VISIT MAY 06

1. Overview:

While conducting research on this topic, one of the authors conducted a site one week visit to MCWL in 29 Palms, California while they where conducting Limited Objective Experiment 2 (LOE2). The author had access to the platoon and the staff conducting the experiment. The intent of the visit was to observe communication challenges if any, and conduct a survey of the experiment participants.

Figure 18. DO Test Platoon and Supporting Staff

The experiment ran from March 13th – May 25th. The author arrived in the week prior to last of the experiment. The platoon used in the experiment came from 1st Platoon, Bravo Company, 1st Battalion, 5th Marines (40% combat veterans from Iraq) from Camp Pendleton. It was the second test platoon to go through this experimental process, the first being 1st Battalion 3rd Marines from Kaneohe Bay, Hawaii during Limited Objective Experiment (LOE1), June 26 – October 20, 2005. The author had the opportunity interview the staff and platoon regarding communications, and those elements that dealt with command and control.

2. General Observations

The DO concept is still in the initial stages of development. The communications infrastructure was RF only and proved challenging to implement. Digital communications is not being pursued mainly because of the voice communication challenges posed by the desert environment.[16] The Command and Control (C2) structure regarding Alpha/Bravo commands and its ideal execution still had some friction points. There were no mobile platforms used in this experiment but some DO vehicles where on hand to inspect for their communications capabilities.

Listed below are key insights from the trip:

- The communications skill set is very basic. The platoon does not have a dedicated 0621, only a 0311 executing the communications voice network.[17] Although

[16] Conversation with the experiment Communications Officer Major Lucus USMC. Providing voice communications proved very challenging in 29 Palms.

[17] 0621 – Marine Occupation Specialty (MOS) Radio Operator. 0311 designator for Infantry Marine.

many of the junior leaders are charged with the operation of radios, training appears to be very minimal. It is important to note that this is not uncommon in the operating forces to have informally trained radio operators within Infantry Platoons. There is no radio operator billet designated with in the platoon.

- Heavy reliance on Tactical Satellite Communications (TACSAT) as primary long haul communications system back to the TOC. Used as a primary net for communications. MCWL was granted 25K channel for use during the experiment. This channel may not be always available in the operating forces given the limited capacity of narrow band SATCOM and use of DAMA (Demand Access Multiple Access)
- The Platoon does not like to use High Frequency (HF) communications. Mobility contradicts time to set up field expedient antennas used in desert environment. Radio operators not proficient on the manipulation of antennas for proper wave propagation.
- Long range communications is the most significant problem with employment of C2 for the platoon. The OTH (Over the Horizon) capability is thought to be a SATCOM LEO solution. Terrestrial communications would be suspect given mountain environment
- No data capability being employed and no push to have data down to the Platoon level or squad level.
- ETCS is an unreliable communications platform which works by some reports only 60-70% of the time. By most accounts from MCWL staff, the system will drop

connectivity for several periods (10 minutes) due to the rotation of the Iridium Satellite constellation.

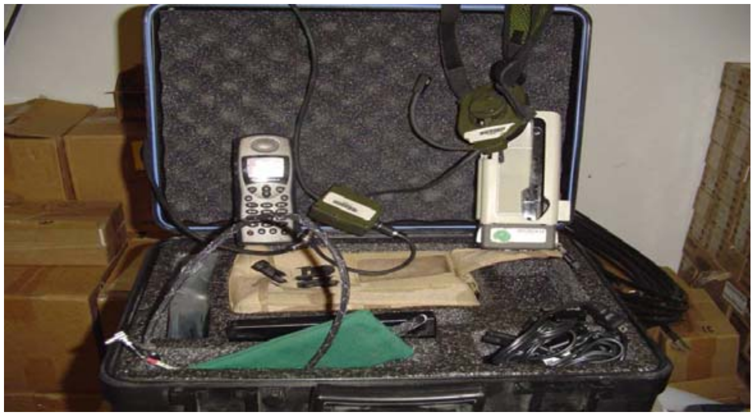

Figure 19. Experimental Tactical Comm. System (ETCS)

- The platoon currently employs one system for both the Alpha/Bravo Commands and one for each Squad. Batteries with an external source are good up to 72 hours. The systems are fragile and do break easily. PLI (Position Location Information) is sent manually by changing channels. Communications via ETCS is virtually a long phone call that does not hang up while the operator has it enabled. The system is relatively simple and easy to manipulate. Operators must manually switch channels to give PLI information. C2PC data resides at the COC. A screen displaying C2PC shows the current location of end users. Time lags and delays are common. Common census around MCWL is an “ETCS like” system is needed to fill this communications gap.[18]

[18] General conversation from MCWL staff believed communications solution with the positive attributes of ETCS was required, although the overall reliability and form-factor of the system was suspect.

- The Marines are weighed down immensely. Some have 150lbs of gear. One Marine weighed in at 315lbs total weight. His bodyweight is only 160lbs. Serious attention to weight must be considered before another piece of gear is proposed for the Marines to carry.

- The platoon uses a small UAV call WASP (Figure 18) for ISR only. MCWL’s intent for this system is to remain purely a binocular “over the hill” capability for each squad. The UAV is “sling-shot” into the sky and is capable of sending real-time video feed to the ground operator. The operator can view the images on a ground control unit or a Tough-book. For the purposes of the experiment the DO Squads were not operating the UAV; rather school trained operators were on sight supporting the experiment.

Figure 20. Picture of WASP

- Power is a major consideration. Under the current DO construct, the platoon would not accommodate high power draw communication assets and the environment

would degrade the function of such assets. However, without tactical vehicles or generators to provide power the ability to communicate could be hampered significantly using only man-packable devices.

3. Platoon Survey

a. Methodology

A 15 question survey generated and administered to the platoon was developed by the authors (See APPENDIX A). Its intent was to grasp the unfiltered responses from the experimental DO platoon regarding communications. The responses then where entered into a web-based application called Survey Monkey allowing the authors to better quantify the results. Additionally the respondents made narrative comments. This provided the authors with key insights on how to pursue their research. Once compiled, the results were given immediately to the MCWL staff for review.

b. Survey Results and Conclusions:

80% (34) of the 43 Marines in the DO platoon were available for the survey. With only 80% of the platoon present for the survey, the authors believe the results are still accurate and worthy of analysis. Those missing would have most likely responded in the Lcpl or PFC categories.

The entire results of the survey are displayed in APPENDIX A. For the purpose of this research, specific questions are addressed regarding communications. Many of the survey participates did have written comments with each question. The authors believe although relevant, reflect the choice response given by the participant and require no further analysis. Here are the general trends:

- Most believe lack of suitable communications is the single biggest factor limiting the success of Distributed Operations. The authors believe this stems from the recent communication challenges experienced by the platoon during the experiment.
- Most believe that each Marine should have some sort of individual communications device but limit larger devices to one or two assets. The Marines clearly understand the value of intra-squad communications but believe larger VHF/UHF assets should be carried and monitored by a few individuals.
- Many (55%) believed that each Marine should be as proficient regarding communications as they are with weapons systems. Almost as many (41%) believed that only designated personnel should operate and maintain such equipment. These responses may reflect the view that each Marine must understand all equipment but only responsible for specific equipment individually assigned.

The lessons of the site visit validated the author’s assumption that the current and proposed communications architecture for DO is inadequate. It also provided a framework in which to pursue methods and technologies that could help DO work more effectively.

The DO platoon current and proposed communications equipment suite does give a great deal more communications capability than ordinary infantry platoons have. The increased capability unfortunately increases

weight and logistic support needed to accommodate the suite. Even with the increased capability, DO units still can not inter-network within the tactical internet used by the rest of DOD. Because of the lack of interoperability of end-systems the Marine Corps still has not address how the larger network infrastructure supports DO. Since none of the end-systems DO employs are routable networks, the authors see this as an unmet requirement.

Since the current and proposed communications architecture for DO is not routable the authors see this as a severe gap and present little to solve joint fires, intelligence and C2 synchronization. No other entity is tied into the DO communication network directly outside of the current T/O.[19] Conversely the supporting communication unit (most cases the battalion communications platoon) for DO can do nothing to manage DO end-systems remotely.

Each radio operates on specific frequencies for a particular reason. By not bridging into a routable network the DO unit severely limits the ability of higher organizations to help support them directly. For example, an intelligence shop, outside the T/O, with actionable intelligence for a DO unit does not have interoperability of end-systems in order to communicate with a DO unit, especially if they are separated physically outside the radio sphere. As it stands today, the computer (end system) the intelligence analyst resides at can not communicate with the tactical radios in the field. Even

[19] No other unit with the exception of line of sight (LOS) communication with aircraft for fire-support or casualty evacuation.

with the ETCS system providing PLI information for the COC, this information was not shared with any other entity on the network.

The LOA-2 experiment in 29 Palms proved extremely challenging for the MCWL communication staff. Long-haul communications provided the toughest challenge by far. Even if this hurdle is overcome, the ability to share voice communications through the tactical internet was neither a priority nor a requirement during the experiment. The authors believe the tactical advantages of DO units are magnified by tying in multiple levels of the organization directly to tactical units on the ground. Since current end-system is not designed for this operation, the authors see this as a capability gap as well.

The authors believe a short-term solution to this problem is feasible. If tactical radios could be integrated more effectively into the tactical internet then unmet requirements of interoperability of end-systems or routable networks could become reality. Once legacy communication systems are successfully integrated into the larger tactical network then advances in technology could more readily replace those systems, communication systems that are designed specifically to be routable and interoperable with other end-systems.

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III. FIELD EXPERIMENTATION

A. FIELD EXPERIMENT DISCUSSION

The primary objective of this research is to demonstrate how the current and future DO communications architecture can be leveraged into an IP (Internet Protocol) network environment. The research investigated the use of Twisted Pair WAVE Server technology to bridge legacy RF (Radio Frequency) communications equipment into a tactical internet in order to determine the capabilities and limitations it provides a DO force and supporting units.

The authors took advantage of the quarterly NPS-USSOCOM cooperative field research program also known as the tactical network topology (TNT) quarterly experiments. Additionally, a wireless network infrastructure exists and is maintained by NPS for ongoing field research. The infrastructure extends from NPS to Camp Roberts Air National Guard Base, approximately 100 miles away. The network is connected via five IEEE 802.16 links and provides over 30 Mbps of data throughput depending on the experiment.

The authors' experimental design tested the implementation of RF-IP technology over various wired and wireless networks. Each experiment built upon the success and failures of the previous. The experiment in (Aug 06) mainly served as a familiarization with mesh technologies and IEEE 802.16 equipment. The second experiment was designed to test the scope of this thesis and determine if and how bridging legacy radio equipment into IP networks could be implemented. The third experiment expanded the

authors knowledge base of the capabilities and limitations of the equipment used. The forth and final experiments were used to gather metrics and quantitative data.

B. TACTICAL NETWORK TOPOLOGY FIELD EXPERIMENT (AUG 06)

The purpose of this experiment was to demonstrate how wireless mesh enabled devices used by a DO Platoon could be used within a larger network architecture. Below is a brief explanation of the equipment used and summary of the results.

1. IEEE 802.16

Figure 21. *Redline* ™ AN-50e (From: [8])

The authors had access to leading technologies in the areas of IEEE 802.16. One of the major technologies used was *Redline* Communications AN-50e equipment. *Redline* is not the sole vendor of IEEE 802.16 technology. They are one of many IEEE 802.16 vendors in the market place. However, the Marine Corps has chosen to procure *Redline* equipment. The TNT experiments rely heavily on this equipment to carry high capacity data within the Camp Roberts tactical intranet as well as to link NPS to Camp Roberts. System characteristics as follows:

- The AN-50e is a high speed wireless Ethernet bridge that can be configured for point-to-point (PTP) or point to multipoint (PMP) operation.

- The system delivers an over the air rate of up to 72 Mbps, equivalent to 49 Mbps at the Ethernet level.
- Operates in the license exempt 5.470 - 5.725 GHz and 5.725 - 5.850 GHz bands.
- In PTP mode the AN-50e adjusts for quality degradation by incrementally switching between modulation schemes from BPSK to 64 QAM.[20]

The authors believe the Redline equipment has many positive attributes, the overall ones is its ability to carry larger amounts of data over long distances and easy of configuration. This is evident regarding one of the five links to Camp Roberts is over 60km in length.

2. Wireless, Ad-hoc Networking

Although mesh networks are not the main scope of this thesis, they potentially may be an integral part of the future DO network architecture. For this reason, an examination of how current legacy systems could be used in conjunction emerging technologies is important to study.

Mesh networks are defined as, "for *n* nodes in a network, the ability of each node to forward information for every other node in the network represents a mesh network topology."[21] For the purposes of DO, a node may be a communications device node used by each platoon member. It could also refer to vehicles equipped with this type of equipment. Additional nodes could be part of the larger network architecture itself. For example, traditional

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[20] Redline Communications. Internet: http://www.redlinecommunications.com/products/AN50e.html, [November 16, 2006].

[21] Gilbert Held. *Wireless Mesh Networks*. Boca Raton, Florida: Auerbach Publications, 2005, p. 2.

communication towers, aerostat balloons or UAVs could incorporate mesh nodes. Listed below are some other key attributes of mesh networks:

- Mesh networks are either connected via point to point (PtP) or point to multipoint (PtMp)
- Every node acts as a radio transmitter and receiver
- Every nodes acts as a forwarding agent
- Every node can enter and leave the network with out disruption to the network
- Each node has an unique identifier, generally the Media Access Control (MAC) or IP address
- Nodes may either mobile or static

For the purposes of experimentation the authors used *Inter-4*™ Corporation’s rugged tactical PDA’s (See Figure 22) configured with wireless *ITT*™ Mesh cards. These embedded *ITT*™ mesh cards provided an Inter-4 software based encryption. PDA’s equipped with these network adapters are capable of providing its users real-time video, voice, SA and chat services within the Mesh architecture. These services could be very useful in a DO environment.

The *Tacticomps*™ were configured at a frequency shifted 2.4 GHz band and employed both *Windows CE*™ and *Windows XP*™ operating systems. The system utilize proprietary software developed by General Dynamics Corporation called *Soldier Tactical Software*™ *(STS)*. These COTS devices are currently being used by some military units operating in Afghanistan and Iraq. *INTER-4*™ was interested in product feedback and allowed the authors to use their equipment for the field study.

Figure 22. Tacticomp Mesh devices. (From: [7])

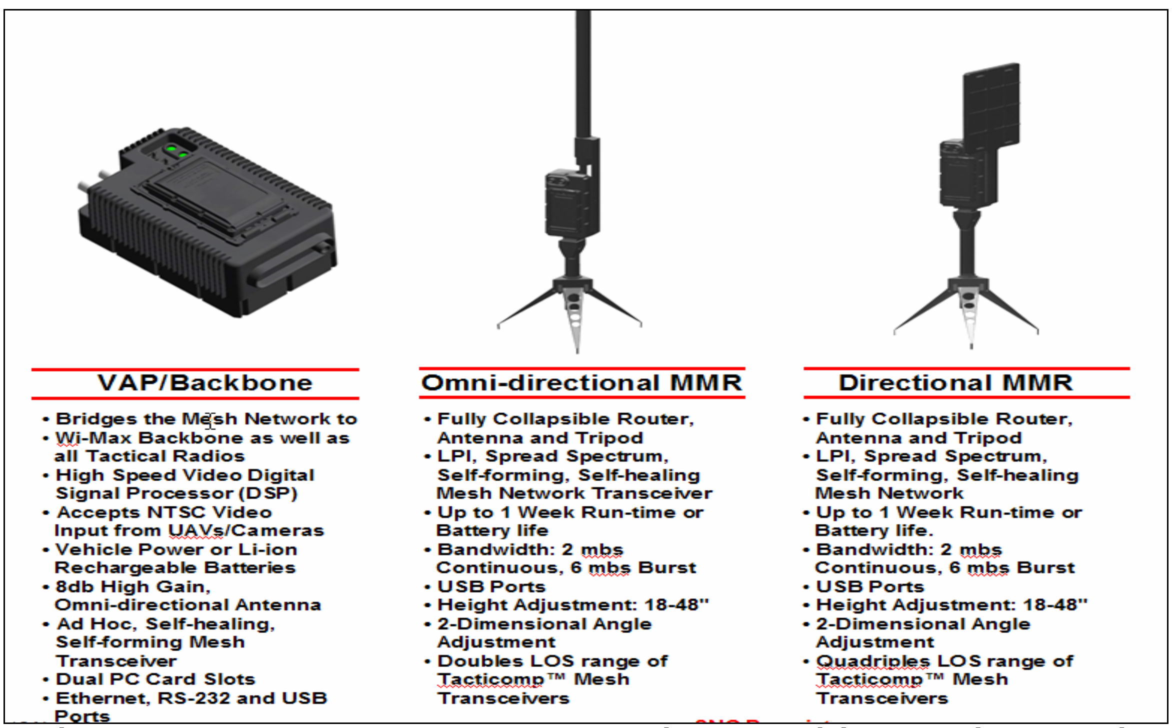

Figure 23. Inter-4 Corp. Tacticomp Bridges and Network Extension Nodes. (From: [7])

The experiment scenarios focused on platoon level and below operations. Each experiment ran consecutively. In scenario one (See Diagram 1) the authors where able to demonstrate encrypted mesh communications over Line of Sight (LOS) and NON-LOS conditions using a Mobile Mesh Router (MMR) (Figure 23) to bridge the gap. Without the MMR, communications would not have been possible. Strategic placement of network nodes proved important to ensure stable communications.

In scenario one (Diagram 1), Squads 1 and 2, are separated by a hill and have no LOS with the TOC. Squad 3 moved approximately 1-1.5Km from Squad 1 and almost 3.5 Km from the TOC. Squad 3 became the focal point in order to push the link. Squad 3 was able to move through Non-LOS terrain with the MMR and still maintain voice and video with Squad 2 and the TOC. All communications were successful up to approximately 3.5Km from the TOC. The TOC was able to see video almost unimpeded while Squad 3 moved.

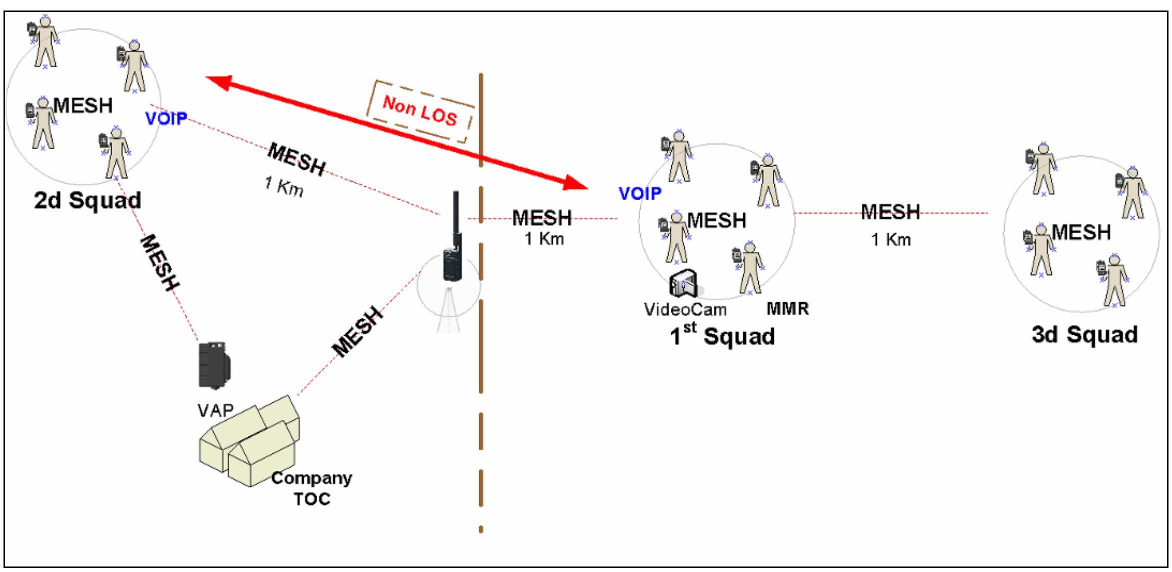

Diagram 1. Scenario 1 Mesh Only.

Each device provided real-time video, chat, situational awareness and voice communications. All applications ran concurrently on each device. At times this proved too much for the operating system on the T-1.5 (Figure 22) which uses a 400 MHz processor. Running one or two applications appeared to be optimal.

The Inter-4 devices are tough to manipulate in terms of simple tasks. The STS software is very robust. In many cases there are two or three ways to accomplish simple tasks. The software should be simplified so that basic tasks are more intuitive.

The terrain at Camp Roberts proved challenging for the equipment and demonstrated significant problems when LOS was lost with another network node. Deep draws or ravines would cause signal loss. The use of the MMR (Figure 23) helped create a larger network cloud to facilitate better communications. In real world applications there ideally would be several network nodes in any given area thus creating a network cloud.

The scenario depicted in Diagram 2 proved very successful. Efforts were directed to bridge the wireless encrypted mesh equipment over terrestrial equipment. The ability to bridge this system over the Redline IEEE 802.16 equipment demonstrated interoperability. Efforts to pass real-time video across the mesh and over the IEEE 802.16 were successful.

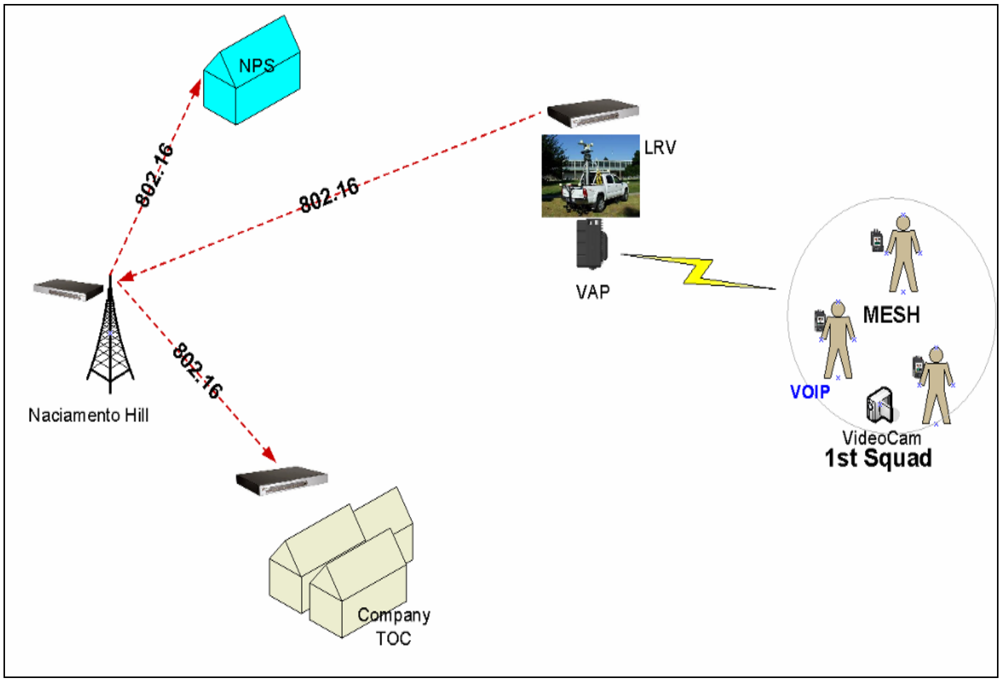

Diagram 2. Scenario 2 Mesh/IEEE IEEE 802.16 Integration

Squad 1 maintained LOS with the Inter-4 VAP (Versatile Access Point) located at the Light Reconnaissance Vehicle (LRV) and had virtually no problems with connectivity. Squads 2 and 3 pushed to earlier positions and had two main nodes in which to connect. The MMR and the LRV (located 1 km from each other on high points) provided the mesh points from which they would connect.

Squads 2 and 3 moved north approximately 4 to 6 km respectfully from the TOC. The LRV acted as the bridge from the mesh network into the broader IEEE 802.16 network. Video was successfully streamed from the LRV to the TOC over the IEEE 802.16 link and subsequently to Monterey. Additionally, video was streamed between Squads 2 and 3 which were approximately 4 to 6 km away.

3. Near-Space Balloon

The authors had the opportunity to use another transmission media that could prove useful for a DO unit. *Space Data Corporation Inc*. was conducting research at Camp Roberts testing their *Starfighter* payload. This payload was used as an aerial relay for voice communications. The company specializes in launching a network of high-altitude network balloons. These balloons are typically launched every 8 to 12 hours to provide overlapping ground coverage. During the experiment these balloons achieved an altitude of 86,000ft and provided a coverage radius of over 400 miles.

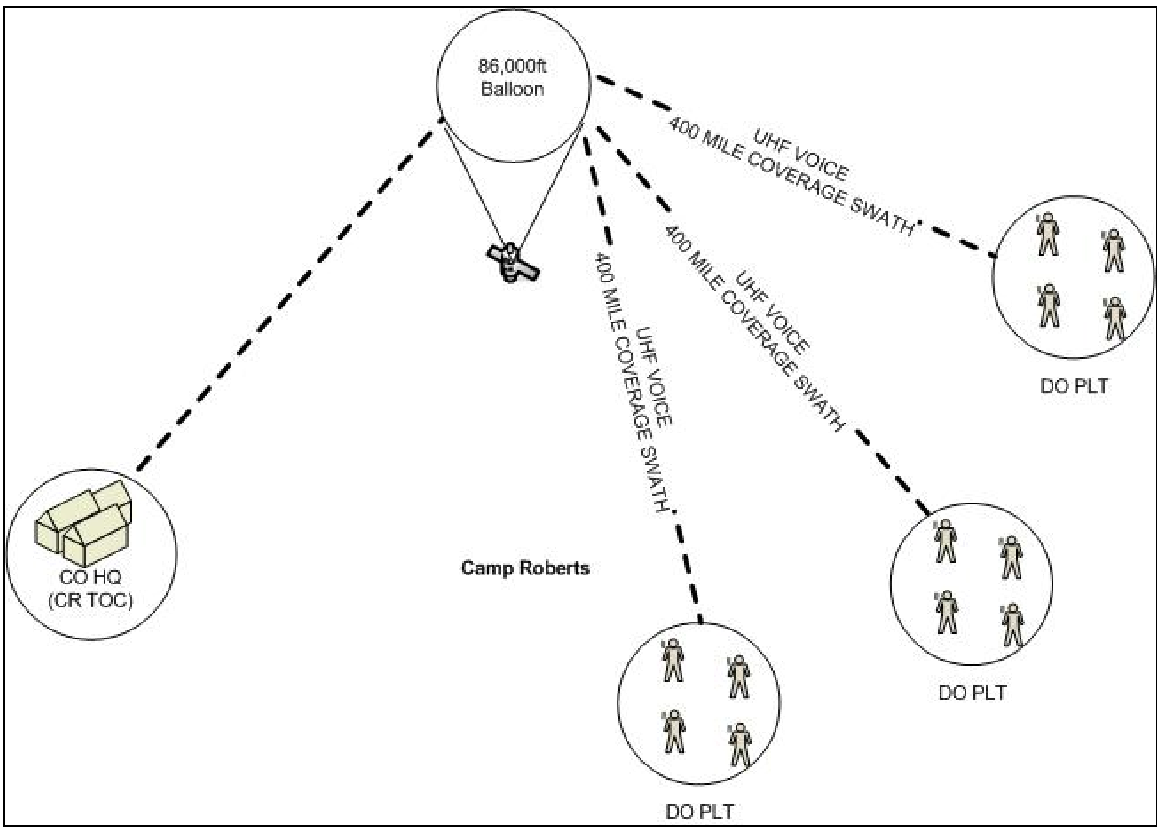

Diagram 3. SDC Near Space Balloon 86,000ft

While working with the *Inter-4* mesh equipment the authors used the balloon payload as coordination net. The company provided two (one uplink/one downlink) frequencies[22] which provided for continuously uninterrupted communications through out the experiment. The signal was re-modulated, there by cleaning up the signal and improving its link quality.

The promise of this technology affords a DO unit the ability to communicate with many of the same characteristics satellite communications have. The main difference is time of flight. Balloons, like LEO satellites, must overlap to provide continuous coverage. Weather is generally not a problem since the balloons operate above the major weather patterns of the atmosphere. Winds do need careful examination for recovery purposes. During the entire flight the balloon is tracked via ground station. Recovery of the payload is a serious consideration. SDC stated they had a 90% recovery success of their payloads.

Currently the company is working with the U.S. Air Force Space Command & Missile Systems Center Test Wing located at Kirtland Air Force Base. Many of their tests show the ability to extend traditional RF communications from 10 to 400 miles using their payload.[23]

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[22] The frequencies provided where in the 300MHz range. It is the authors understanding the payload acted as a “bent-pipe” rather than reprocessing the signal.

[23] Space Data Corporation. Internet: Press Release, August 30, 2006 http://www.spacedata.net/press083006.htm ,[December 13, 2006].

4. Conclusions

The use of wireless mesh equipment for DO does have great potential. Platoon level and below tests demonstrated shared situational awareness, real-time video and chat capabilities which under the current DO architecture is limited in scope. Additionally it was demonstrated that encrypted wireless mesh network could be bridged across terrestrial IEEE 802.16 networks. This holds great potential for high bandwidth communications in support of distributed forces.

The authors believe the VoIP feature of the Tacticomps for short distances can be useful and may relieve a DO platoon of the need to carry a PRR for intra squad communications. The mesh network could facilitate this and provide more robust performance using other applications such as chat and video. The form factors of Tacticomps, however, are undesirable. Though lightweight, the Tacticomps are bulky and require the user to hold the device like a palm pilot. It is also unlikely that Marines would use hill tops as patrol routes rather using the military crests and slopes. This is a negative factor for mesh, where LOS is vital for network performance. The experiment did not go into an urban environment therefore the stress of the network was not really tested. VHF voice communications would and did work better in NLOS conditions; therefore network reliability of mesh is an issue.

The mesh equipment did provide the squads much more capability than they would otherwise have. The obvious answer for many of these NLOS issues is providing a node in the sky or some sort of unmanned platform. These

capabilities were not explored but should be in order to see the full potential of such architectures.

In the end, the experiment did provide some great potential for routable mesh architectures. It also demonstrated how a tactical network could be easily integrated into the larger IEEE 802.16 network backbone where anyone on the network with the right software could easily see and talk to a DO platoon in the mesh network

The use of near-space balloons may provide the footprint needed for DO. The ability to have a 400 mile swath of ground coverage would solve many of the LOS problems associated with DO. Balloons could be launched and recovered from the sea where probability of payload loss would be diminished greatly since the likely hood of littoral regions would be secured by U.S. forces.

Both examples demonstrate possible solutions for DO. The robustness of wireless mesh using near space balloons as network nodes could be one answer. In either case, the use of these networks could facilitate the transport of networked voice communications. Once the network is established, the bridging RF legacy equipment into the architecture could be accomplished. The authors believe further research should be pursued in both of these areas to determine whether these technologies can be leveraged for distributed operations.

C. TACTICAL NETWORK TOPOLOGY FIELD EXPIREMENT (OCT 06)

The goal of these experiments was to demonstrate utilization of legacy RF radio systems bridging into existing networks. The tactical integration of legacy radio equipment into long-haul IP links and tactical mesh networks look to provide better integration of existing

Marine Corp network protocols. This experiment focused on the integration of the same ground radios used by DO and other Marine forces.

1. Background:

Distributed Operations (DO) is an evolving concept that seeks to maximize the Marine Air-Ground Task Force (MAGTF) commander's ability to employ tactical units across the nonlinear battlespace. Currently, the DO platoon is being equipped with extra HF/VHF/UHF radios and limited Iridium-based communication assets to address the tactical communication requirements of the distributed force.

This research focused on the bridging of legacy equipment that is currently supplied to USMC DO platoons and interfacing with an ever growing tactical LAN architecture. As data is being pushed to the last tactical mile[24] and Marine Corps infantry battalions now are equipped with tactical network capabilities. The authors contend research demonstrating the practical bridge of legacy equipment into tactical IP infrastructures could better facilitate Distributed Operations. Key leaders (Squad Leaders and Fire Team Leaders) are already equipped with PRC 148s, PRC 117Fs and PRC 119F radios to support communications. Therefore research efforts should include networking current legacy radio equipment.

This research focused on allowing Battalion Commanders and staffs the ability to use the tactical IP infrastructure currently in place to facilitate voice communications to their DO units who may be well beyond

[24] "last tactical mile" refers to military units who have never before had access to data links normally afforded to upper echelon units. In this case infantry company and below are the last tactical mile.

traditional RF ranges. This experiment demonstrated that as long as a DO unit has an interface with the network then anyone on that network can use their IP-based device to interface with legacy RF equipment.

2. SPEED Analysis

Speed (Systems Planning, Engineering, and Evaluation Device) is a communications planning software tool developed by Northrop Grumman Corporation. SPEED is a fully integrated system for generating, storing, and disseminating communications information. SPEED provides rapid communications planning and support and was used for the link analysis for this experiment.

In all of the experiments SPEED version 10.0.1 was used to test the viability of the communications links before actually deploying into a field environment at Camp Roberts. SPEED accounts for equipment parameters and terrain characteristics among other variables that affect communications. The software allows for easy analysis to determine if a link is viable. Adjustments can be made to determine the right location of antennas and placement of the equipment used.

a. SPEED Analysis – IEEE 802.16 Redline Equipment

Experiment 1 demonstrated the viability of the link between terrestrial radio equipment. In this case, IEEE 802.16 Redline AN-50e equipment was used for LOS analysis. Equipment and link parameters are detailed in the Figures below. Each figure provides details on radio settings and specific parameters of the equipment. A solid line indicates an acceptable link. A dotted line indicates an unacceptable link.

The authors attempted to closely match the radio and network settings used by the TNT experiments. Speed accounts for terrain elevation and specific characteristics of the radios. It is the opinion of the authors that this analysis provided a fairly accurate assessment of the feasibility of each radio link before the actual experiments began.

Figures 24 and 25 demonstrate LOS communications between the TOC located at McMillan Airfield and Nacimeiento Hill to the west. LOS communications with a distant node 10 kilometers to the north are also achieved.

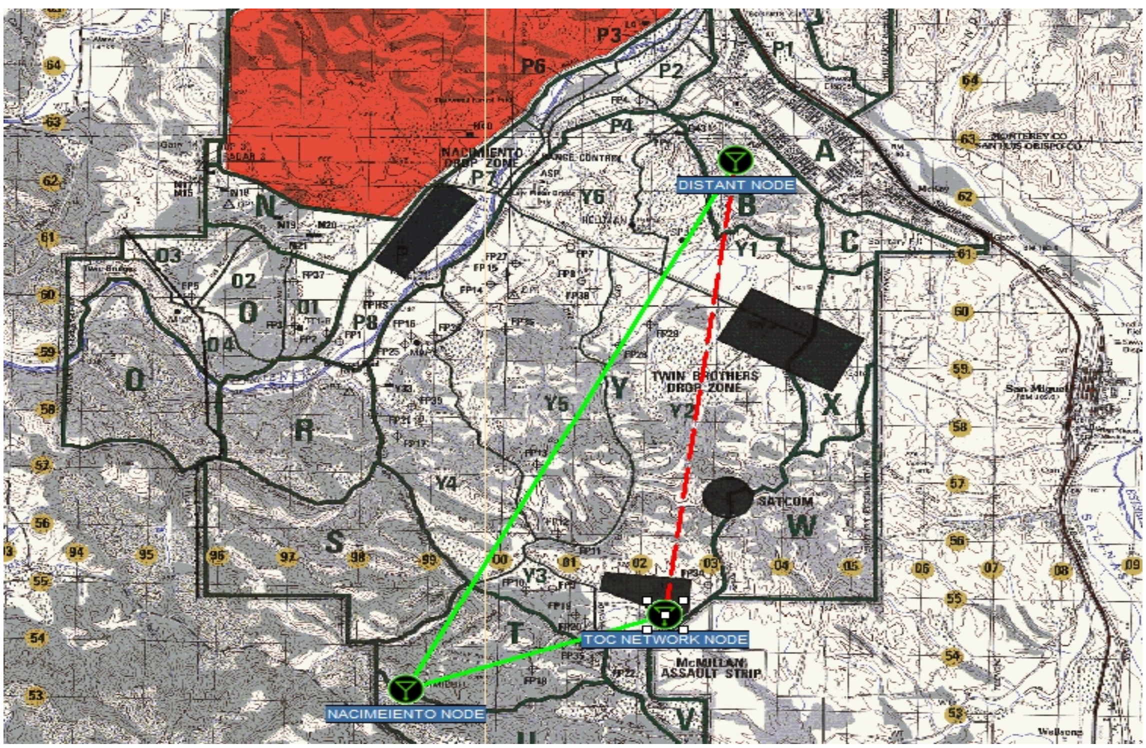

Figure 24. Redline AN-50 Link Analysis

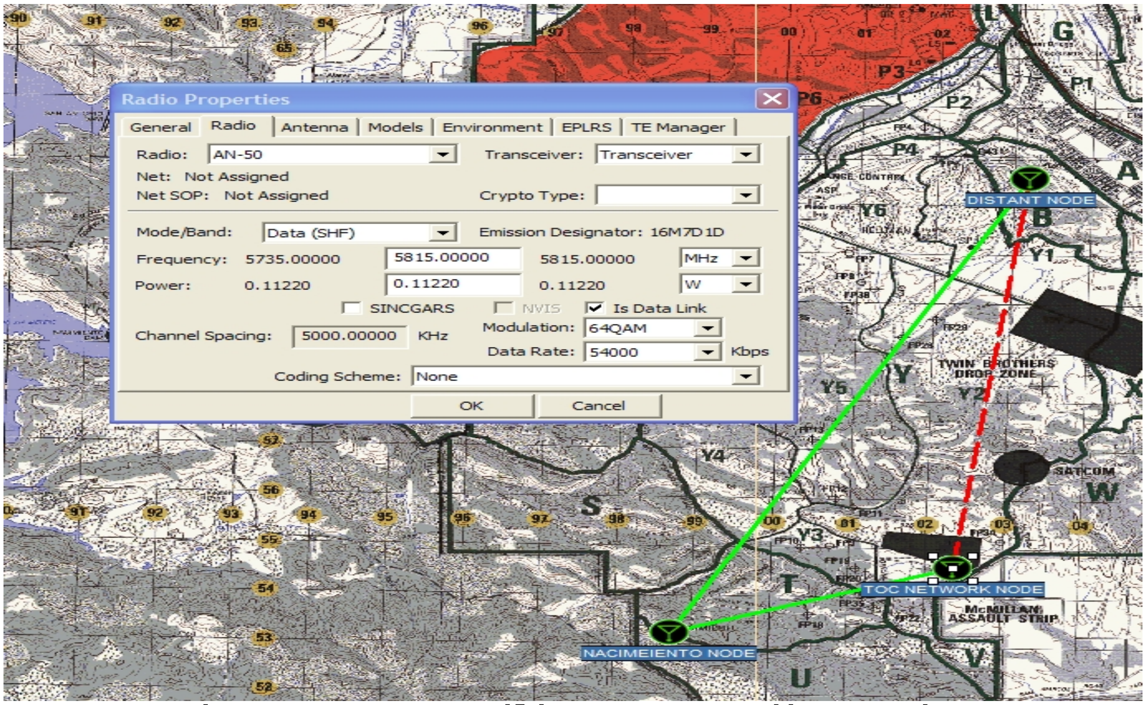

Figure 25. Redline AN-50 Radio Settings

Figure 26 depicts a LOS link from Nacimeiento Hill to a distant node in the field. For purposes of the experiment, the authors investigated how a DO platoon (distant node) would link into the network when there was not LOS directly with the next higher echelon unit. It is not important to have this link collocated with friendly forces but merely within the RF sphere. By extending the network link, the RF-to-IP connection can be anywhere the RF coverage exists.

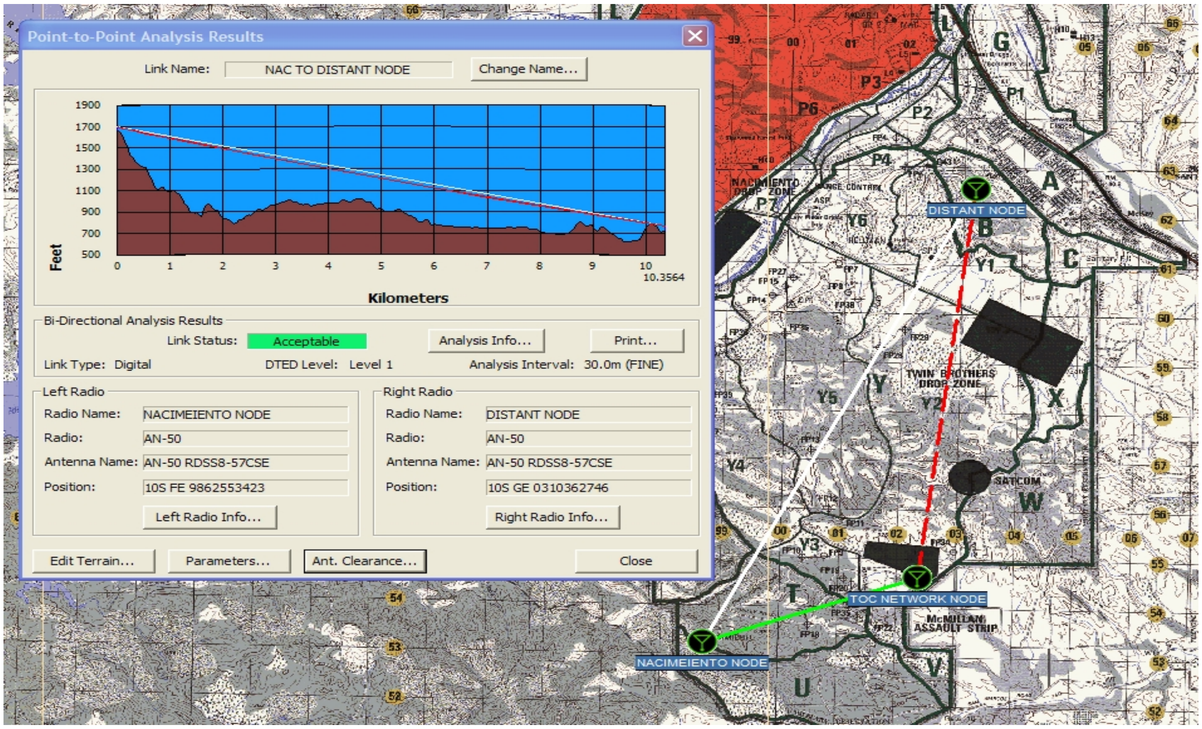

Figure 26. Point-to-Point Analysis from Nacimeiento Hill to Distant Node.

b. SPEED Analysis – VHF Equipment

Legacy radio equipment performs poorly for long range communications. The dotted red lines depicted on Figure 27 depict the inability of VHF communications to supply coverage at ranges only 8-10 kilometers from the TOC. However, much depends on the terrain, power and type of antenna used. In the analysis the authors attempted to match the approximate power settings typically used by foot-mobile ground forces.

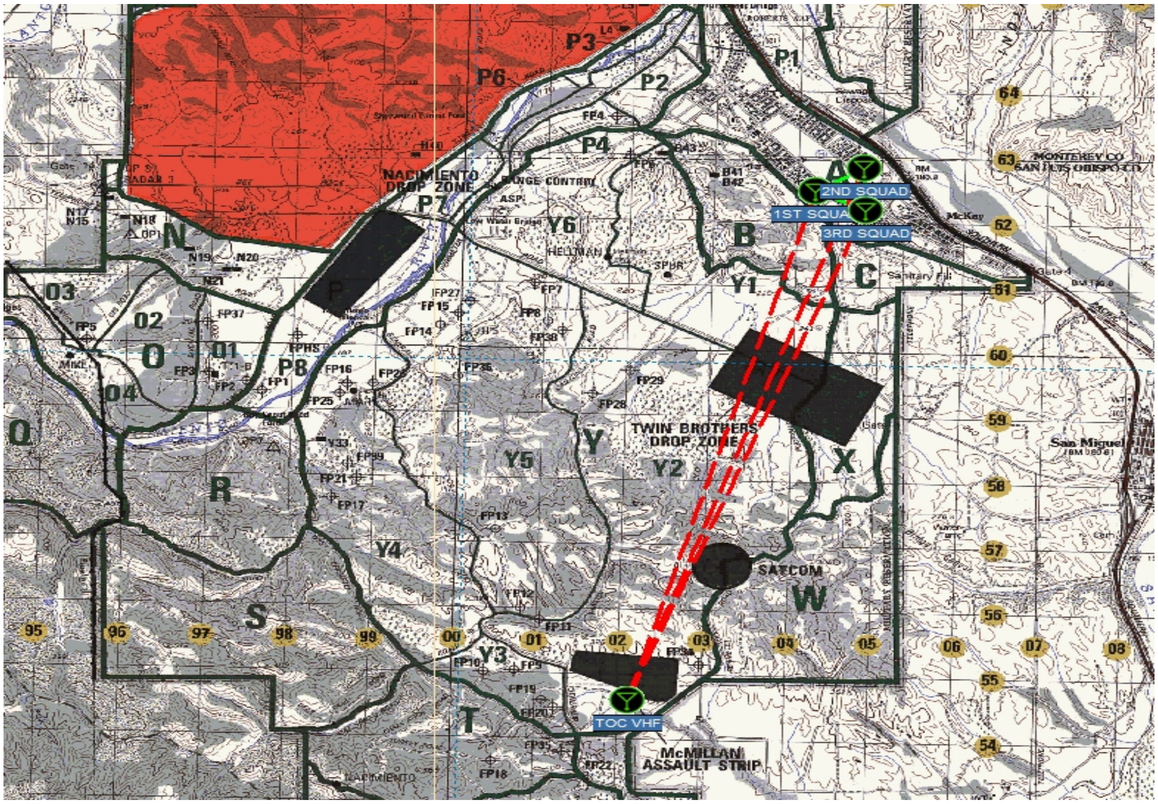

Figure 27. Unacceptable Link from TOC to DO Plt.

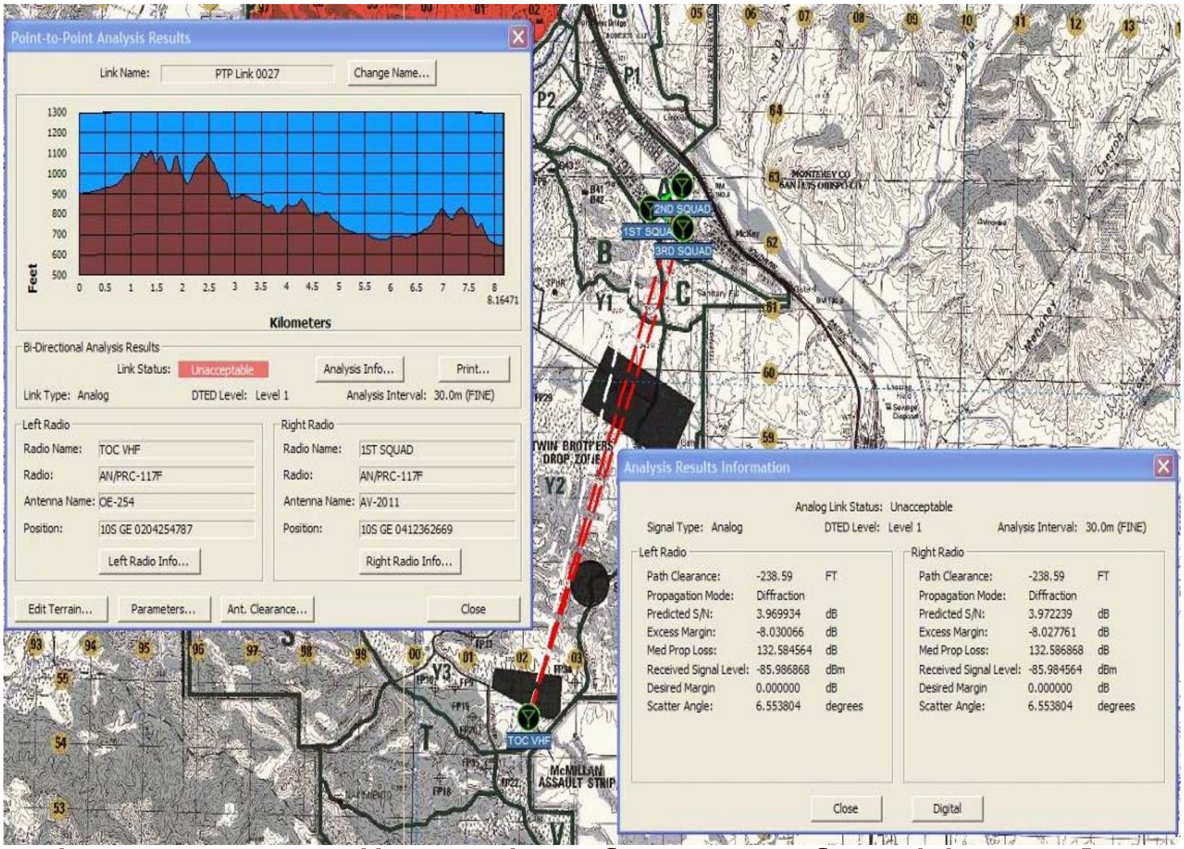

Figure 28. Radio Settings for PRC 117f used by DO Plt.

Unacceptable links are caused mainly from terrain as shown in Figures 27 and 28. The graph inside the figure indicates several hills between the TOC and the distant nodes. Even though VHF can propagate well in rolling terrain, it does not perform well in this scenario.

This analysis provided insight into possible communication difficulties a DO unit may face working merely with VHF radios. The use of RF-to-IP communications greatly extends the network architecture to the forward deployed marine.

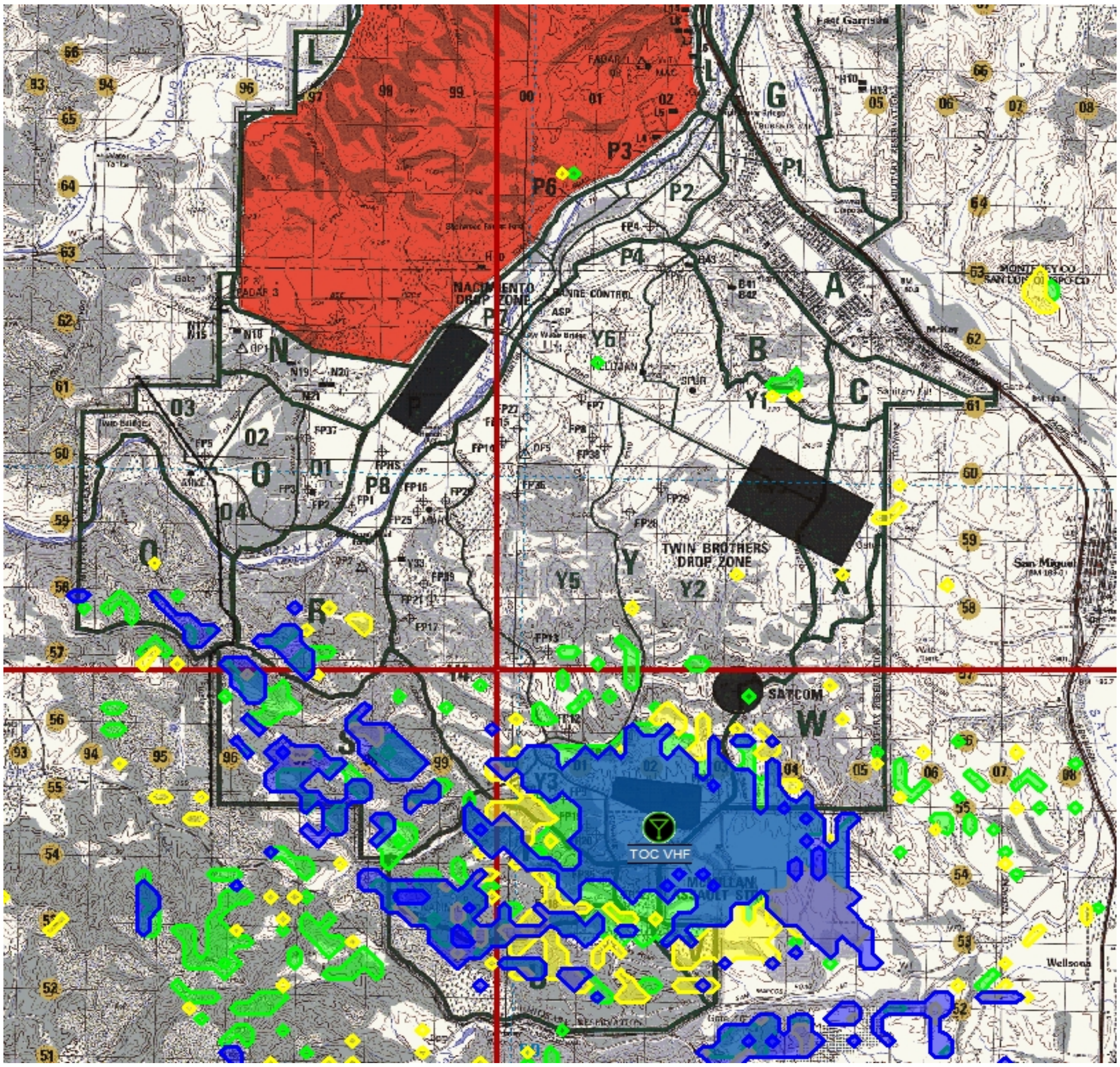

Figure 29. VHF Coverage Pattern for PRC 117F at the TOC

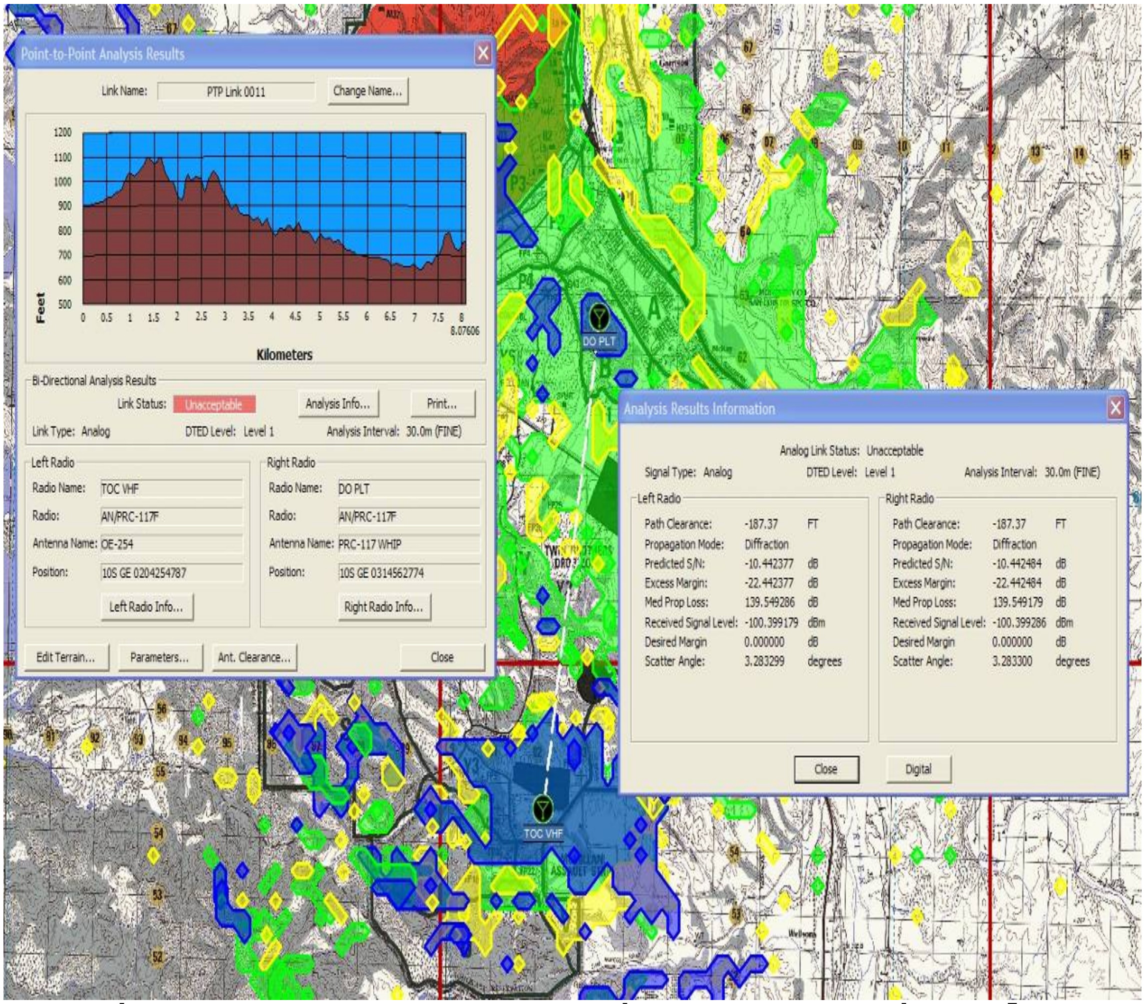

Figure 30. VHF Coverage between TOC and DO Plt.

c. Speed Analysis – MESH

Speed does not have operating characteristics for ITT Mesh cards in its database. Therefore, the authors substituted SECNET-11 cards in the SPEED database as a substitute. They possess the relative frequency range and power used for field study. Figure 31 illustrates the possible PtP link between ITT Mesh nodes in the field. Only the ITT MESH balloon node maintains connectivity with the other nodes. This is depicted by the solid lines of from the balloon vice the dotted lines of the other nodes in Figure 31. For analysis purposes the balloon's altitude

is 3500 feet. Figures 32 & 33 demonstrate the coverage pattern with and without the use of the balloon. Shaded areas depict existing RF coverage. Due to its altitude, the balloon greatly enhanced network coverage. Figure 32 demonstrates coverage without the balloon to be unacceptable. Figure 33 demonstrates the LOS coverage pattern out to 8 kilometers. The use of multiple high altitude nodes would significantly increase the coverage radius of those nodes within its footprint.

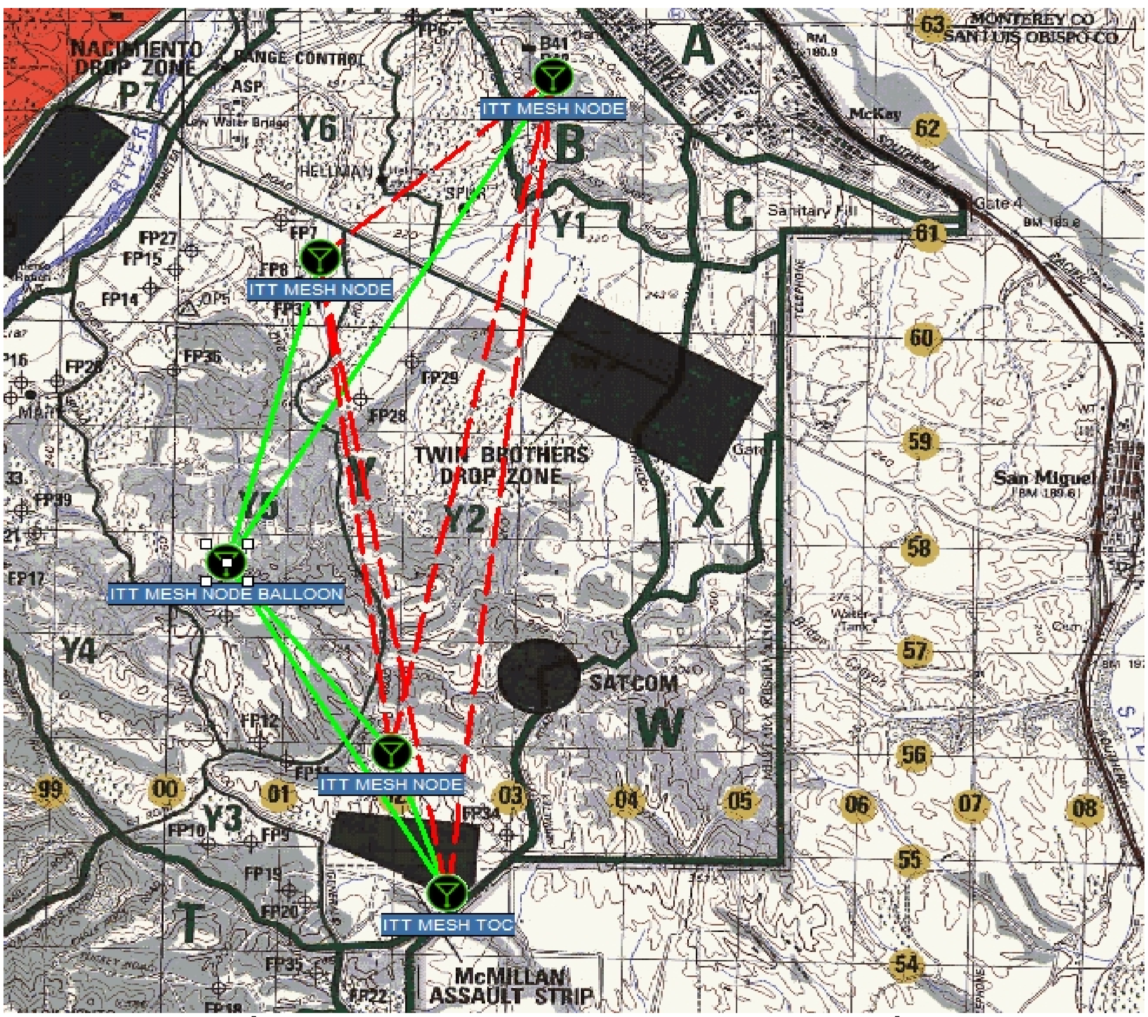

Figure 31. ITT MESH PtP Connection

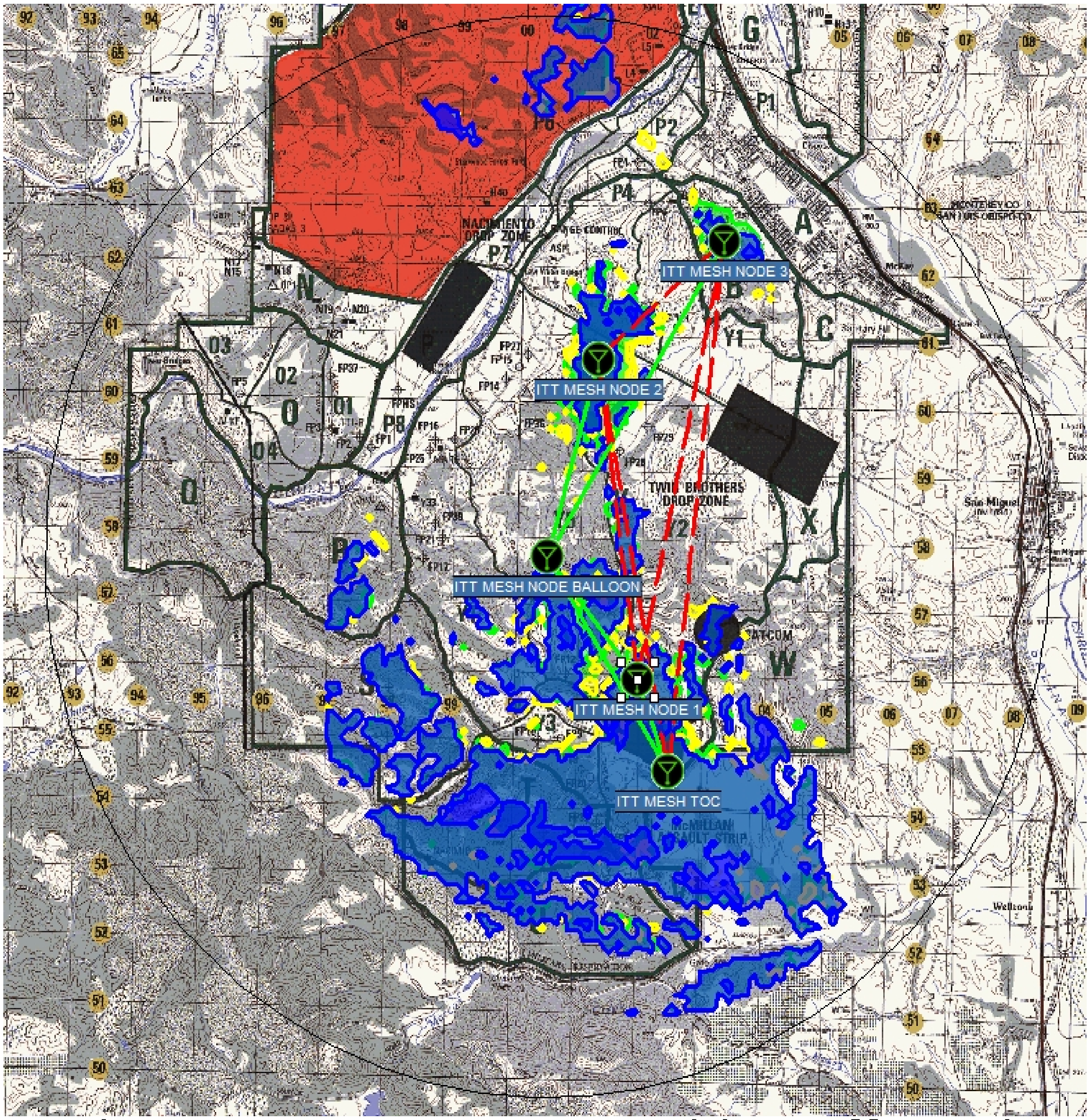

Figure 32. ITT MESH Coverage Without Balloon Node

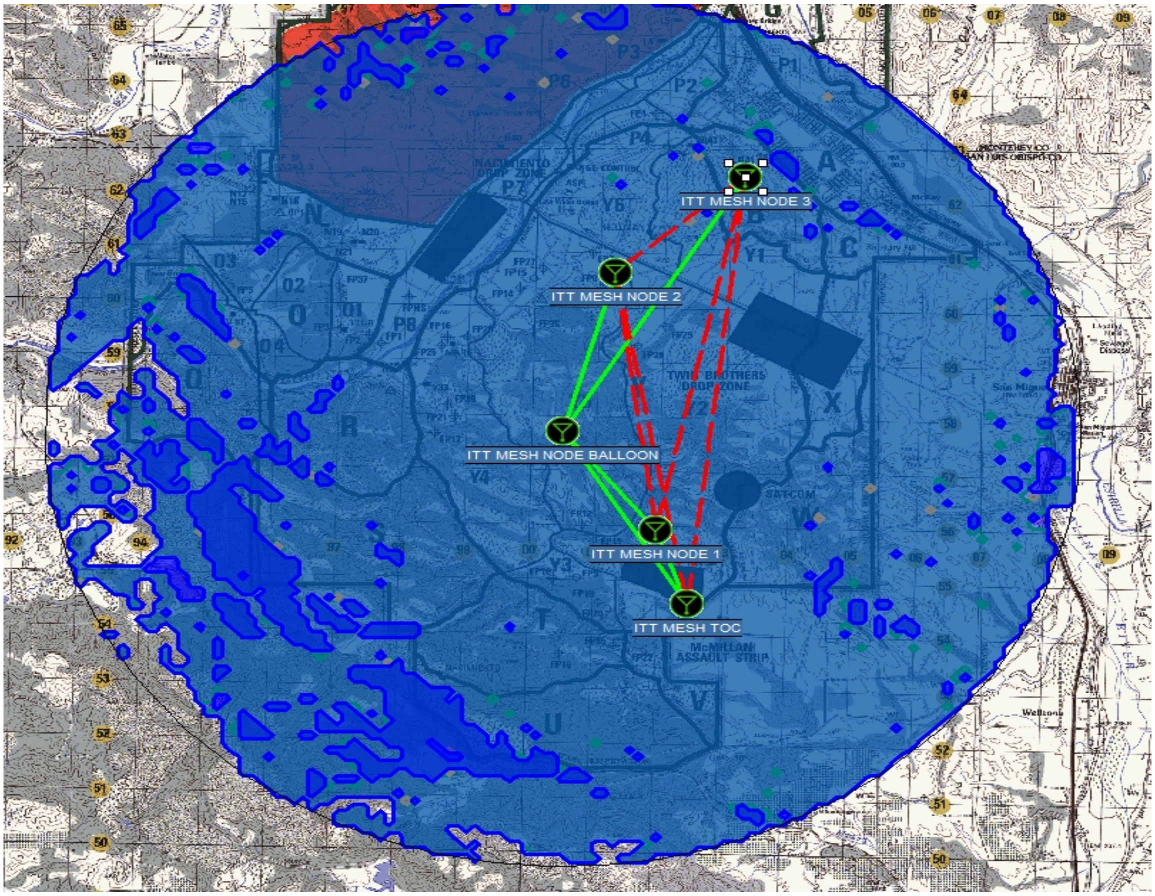

Figure 33. ITT MESH With the Balloon Node

d. Conclusions

The SPEED analysis provided a solid baseline from which to conduct field study. Examining the feasibility of the various equipment used in the experiment allowed the authors to make more accurate assumptions. Signal propagation under specified equipment parameters gave a practical assessment of various terrestrial radio equipment would perform at Camp Roberts. Additionally, examining the coverage patterns of legacy VHF radios and ITT MESH cards helped show the effects of terrain. In each analysis SPEED allow the testing of equipment settings without field study. The authors believe this type of analysis helps take much of the guess work out of the research and enforces or negates assumptions by the authors.

3. Experiment Assumptions

- The DO unit (Company or Platoon) are equipped with the proposed field communication assets dictated by the Marine Corp Warfighting Lab (MCWL). All units are using Type 1 encryption.
- The DO Platoon is within normal RF ranges (< 5 Km for manpack and < 15 Km for vehicular) of a long haul link. In this case IEEE 802.16. Diagram 4 illustrates basic setup.
- Long-haul links are tied into larger IP network infrastructures. For the purposes of this experiment the TNT architecture is used. Diagram 4 demonstrates an IEEE 802.16 link only. For practical purposes the medium could be any Layer 2 or 3 technology providing access into a tactical internet infrastructure.

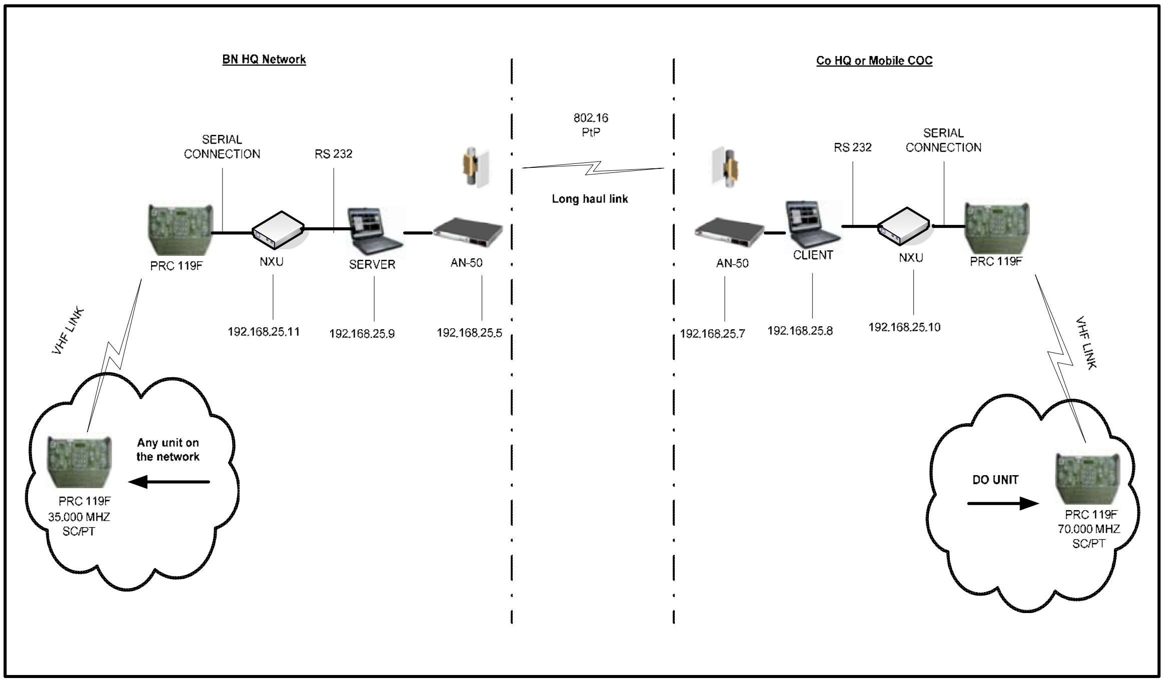

Diagram 4. Basic set up.

4. Equipment Technology Used

a. Radio Hardware

- (3) Harris PRC 117F VHF/UHF Radio
- 1 AC to DC power supply
- 1 Speaker box with H250 Handset
- (1) Harris PRC 152 (VHF) Hand Held Radio
  2 rechargeable batteries w/charger
- (4) PRC 119F VHF Radios - SL3 Complete
- (4) PRC 148 Radios (MBITR) - SL3 Complete and two BB390 rechargeable batteries each
- (1) SkyPilot System
- (4) Panasonic Tough books
- (6) ITT Mesh Cards
- (3) Raytheon NXU2 (RF to IP converters)

b. NXU2-A™

There are numerous hardware and software applications for converting the serial data from tactical radios into an Ethernet frames. Among the most common are E/M (Ear/Mouth) cards used in routers. These cards take the four-wire signaling from the radio, along with the push-to-talk ground closure and convert them to IP packets. We chose the Raytheon NXU2-A for our radio to IP interface. This interface is modularized, small, easily configured, and easily updated with test settings. The NXU2-A is also cheaper than a router populated with the needed E/M cards. The NXU2-A is a fairly new device on the market compared to the router cards and is also newly added in the software product line provided by the WAVE software used in our testing.

Figure 34. NXU2-A

The NXU2-A is configured via a serial interface cable or a remote web interface. Once connected to the configuration page of the NXU2-A, numerous configuration operations are available. The options provide for easy configuration of various radio applications. The ability to change VOX levels, IP addresses, voice encoders, and connection modes to name a few.

c. Sky Pilot System™

The Sky Pilot System was another transmission media used in support of our experiments. Sky Pilot uses the IEEE 802.11A wireless protocol with directed antennas providing extensive ranges. The authors were given a *SkyConnector* to use to connect into the experiment IEEE 802.16 network. The *SkyConnector* provides an Ethernet drop to the subscriber and connects to the high-capacity wireless mesh network through a directional 5 GHz link. The connector is capable of ranges up to 7.5 miles/12 km NLOS. The networking capabilities of the Sky Pilot network also facilitate the ease of seamlessly adding and removing nodes within the network. The system operates in the 4.9 to 5.8 GHz range of spectrum and consists of several different models as depicted in Figure 35.

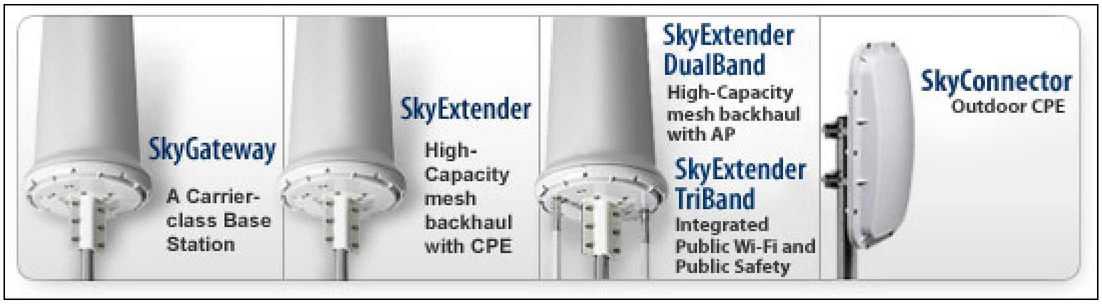

Figure 35. Sky Pilot System (From: [30])

d. Twisted Pair WAVE™ Software

Twisted Pair WAVE MEDIA SERVER™ (SP3 Beta Version) is a gateway computer designated to mix audio channels for the WAVE application. The media server software also provides the tones required for IP phones to key certain radios. The media server software provides mixing of audio signals from different users into WAVE “sessions”. These sessions determine what WAVE “channels” are provided to individual users on VOIP devices. These VoIP devices include computers running WAVE’S Desktop Communicator, configured IP telephones, Plain Old Telephone (POTS) devices, cell phones, and more. The media server hardware is determined by the number of users. Since there were never more than 25 users during our experimentation, we were able to run the WAVE media server software on the WAVE Management Server.

Twisted Pair WAVE CONFIGURATION MANAGER™ contains all of the configuration data for participants in WAVE sessions. A central administrator will create user accounts with numerous options for access. Access includes monitoring only, transmit capability, and access to different sessions. The Management Server Administrator

configures channels for audio participants on the network. A session is then configured which allows users access to different channels. A session may provide a user with a number of different channels to include radio networks, audio streams, phone conferences, and paging channels.

Twisted Pair WAVE DESKTOP COMMUNICATOR™ is a PC application which allows users to access channels and can be loaded by logging onto the web page for the Management Server. From this web page the Desktop Communicator software is downloaded over the network onto the users' PC. The Desktop Communicator logs onto the Wave Management Server and opens the channels that are available to that user. Depending on the access granted by the administrator, the user can transmit on a channel, text message other users that are online, monitor audio on individual channels, mute channels, and more.

The Desktop Communicator gives the option of logging in via a unicast connection. The unicast function is helpful when the user is logging in from a remote location which does not support multicasts, such as over the internet or through a Virtual Private Network (VPN). Unicast was used exclusively during our experiment as multicast was not enabled on all switches and routers in the experimental deployed networks. Multicast was not an option while using the MESH networks for relaying voice traffic as well.

5. Field Experiments and Demonstration Technologies

Legacy radio equipment was examined for RF over IP integration. The authors used the established long-haul IEEE 802.16 connection from Camp Roberts to NPS, to demonstrate military VHF voice integration over an IP

network infrastructure. This experiment investigated voice quality over a 100 mile link using legacy radio equipment over the IEEE 802.16 waveform. Further attempts to mimic the actual mobility of DO units on each distant end and allow those units to communicate at extended ranges were investigated.

The actual experiments simulate a DO Platoon (Diagram 5)conducting distributed operations in the vicinity of McMillan airfield in order to locate and defeat enemy forces and destroy encampments in the AO to prevent the spread of insurgent forces. The IEEE 802.16 link depicted in Diagram 5 is specific to this experiment but could represent any link providing access into a tactical internet infrastructure. The intent here is to establish RF-to-IP integration using the WAVE software and NXU2s.

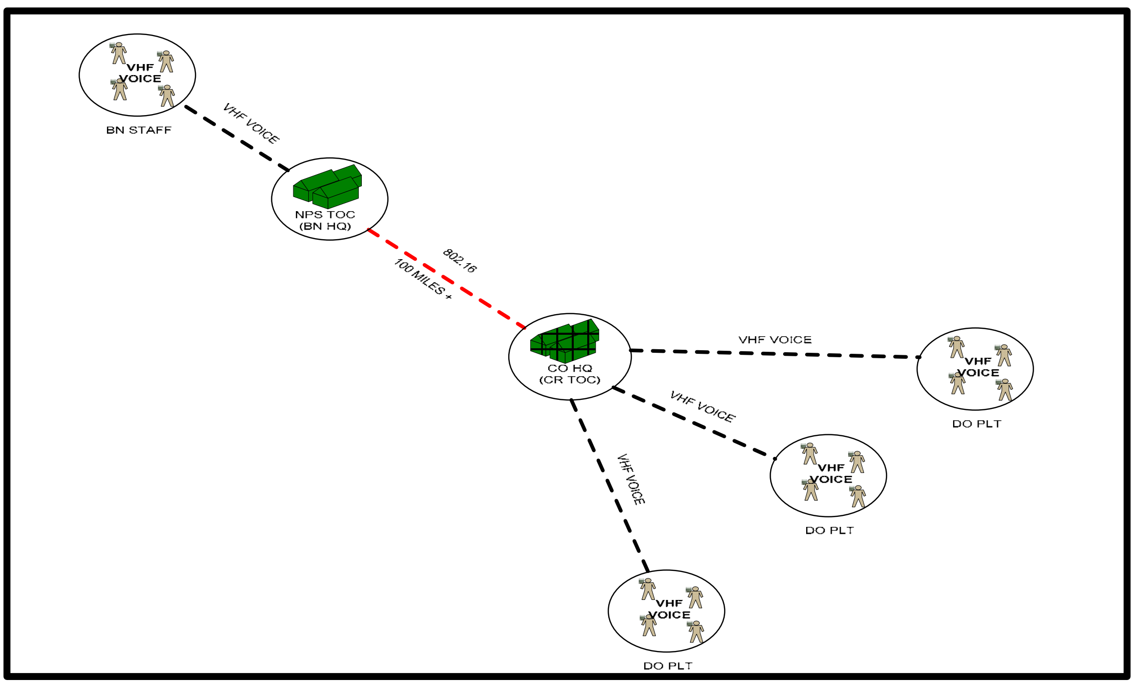

Diagram 5. DO Exp 1 - Legacy VHF voice over IEEE 802.16 network

a. Test Results

The WAVE server was installed in the Tactical Operations Center (TOC) at Camp Roberts. One AN/PRC-117F was connected to a NXU2 at the TOC. This central node was connected to mobile users via a Very High Frequency (VHF) covering up to 6 kilometers of hilly terrain with minimal vegetation. The network was connected back to the Naval Post Graduate School (NPS) via a Redline IEEE 802.16 backbone.

A user staged at NPS was using Desktop Communicator to monitor and coordinate traffic on the network. The NPS user was able to successfully communicate with the handheld radio operator that was mobile on Camp Roberts. The mobile radio operator was also able to communicate back to the NPS user over the IEEE 802.16 network. There were no latency, or jitter problems encountered and voice quality and availability was excellent.

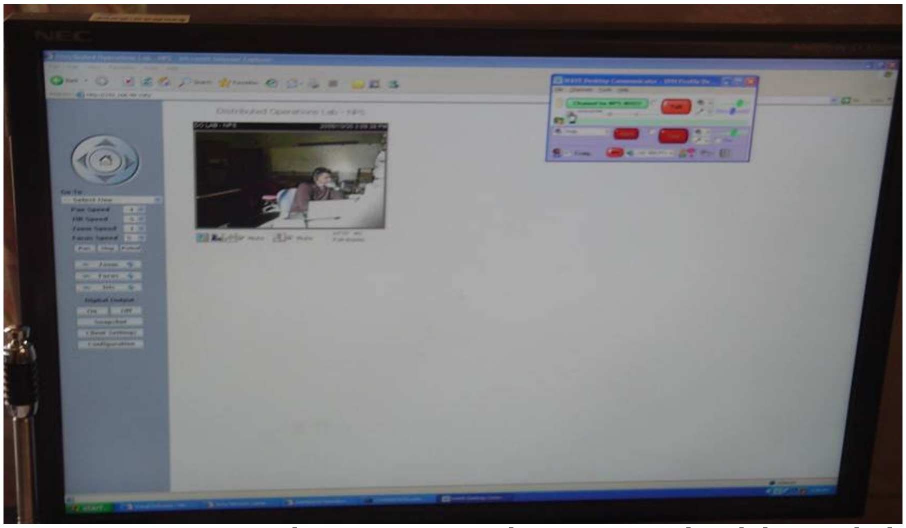

Figure 36. Desktop Communicator and Video Link to Monterey

Figure 36 shows the NPS user talking over desktop communicator to a user at the TOC on Camp Roberts. The connection was via a Redline IEEE 802.16 link. Distance for this connection was over 100 miles. Distance from the TOC to radio users was over an average of 6 kilometers.

Experiment two investigated a shorter PtP link incorporating the *SkyPilot* IEEE 802.11A technology into the network. The authors used the services of WINTEC Corporation to provide LOS communications to the broader IEEE 802.16 network used by TNT. Once this link was established, RF to IP voice was transferred back and forth from DO platoon to the TOC via the IEEE 802.11A network. The mobile ground unit passed voice traffic thru this link to the TOC and also the network lab located at NPS. **(See Diagram 6)**

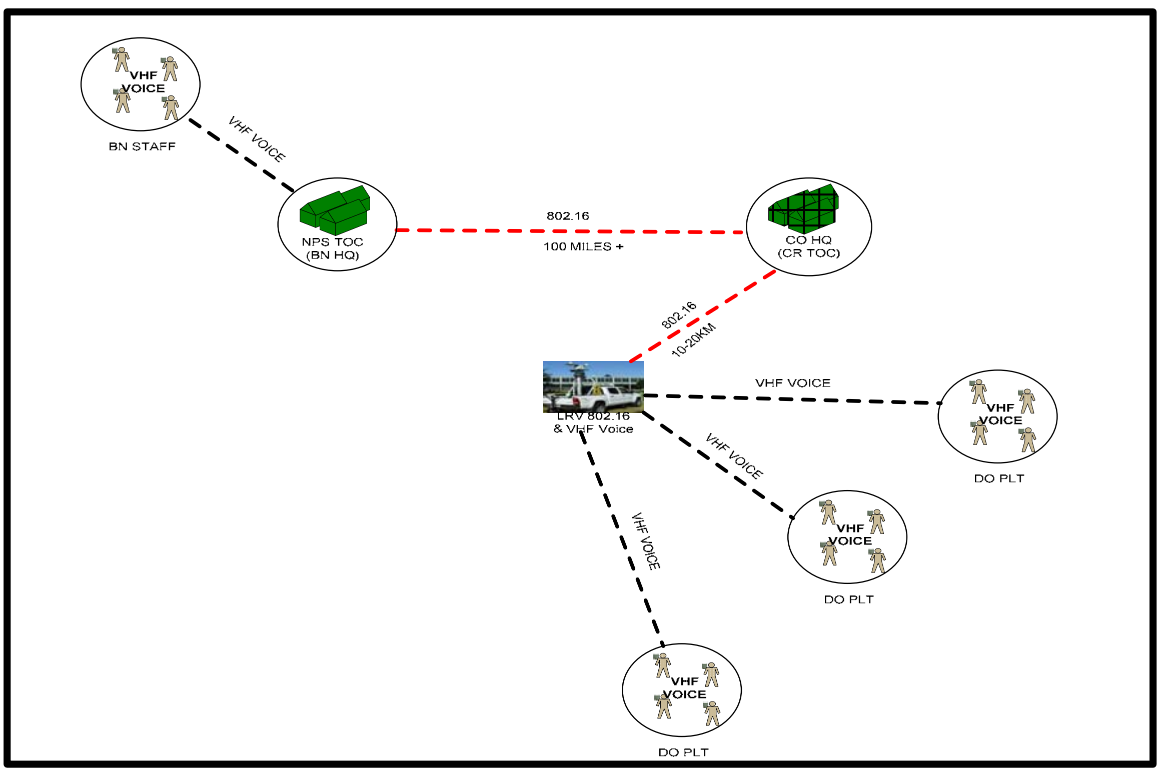

Diagram 6. DO Experiment 2. LRV IEEE 802.11A Integration

The LRV established an IEEE 802.11A link with CR TOC via Naciamento Hill and used a PRC-119F to communicate with the DO Platoons. The LRV used a laptop and WAVE desktop communicator to talk to the DO platoons and used a PRC 117F to communicate to platoons for redundancy. Co HQ (CR TOC) communicated via IEEE 802.11A to the LRV and then IP to RF to the DO platoons.

Figure 37. IEEE 802.11A Sky Pilot System Into IEEE 802.16 Network

Figure 38. Desktop Communicator & NXU2

This test demonstrated the use of the Sky Pilot system to provide long haul over the horizon connectivity to the NXU2-A. A mobile radio operator displaced a Sky

Pilot extender beyond the Radio Frequency (RF) range of the TOC. From this location the operator was unable to communicate with an AN/PRC-119F on a VHF frequency to the TOC. The operator connected the AN/PRC119F to the NXU2-A and connected the Ethernet output of the NXU2-A into the handheld Extender. The extender connected via IEEE 802.11A to a Sky Pilot network of Gateways connected to the TOC. The radio operator was then able to drive around with another AN/PRC-119F and talk on a VHF frequency. The radio operator was able to get an average of 6 kilometers of distance from the Sky Pilot extender before using VHF RF coverage. This enabled the operator to talk at a distance of over 12 kilometers on a 4 watt VHF transceiver to the TOC. The operator was also able to talk to the NPS operator over 100 miles away via the combination of the VHF, Sky Pilot, and IEEE 802.16 network. The TOC and NPS operator were also able to effectively transmit over the respective networks to the radio operator in the field.

Experiment three added different end systems in to the network such as IP phones and laptops. This demonstrated how a user could manipulate different IP based devices (See Diagram 7) to communicate using a PRC 119F (or similar legacy radio) in the field. Or if configured properly, use multiple devices from separate physical locations on the network, to communicate as required. This investigated the ability to give more individuals greater situational awareness of the battlespace and further tied in key supporting roles into direct link with forward units.

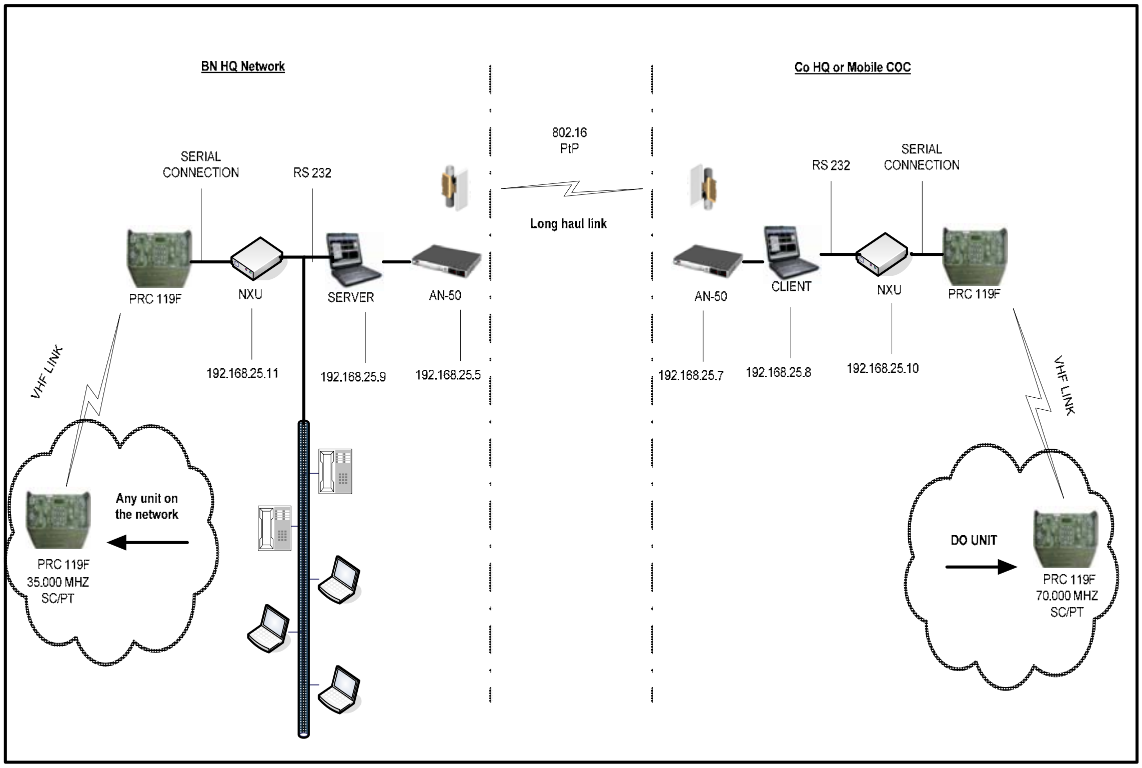

Diagram 7. Experiment 3 Additional Node Integration

The Cisco IP phone was configured to operate on the Cisco Call Manager installed in the TOC. The WAVE Server was configured to give access to all tested radio channels on the IP phone. Once logged in via the IP phone, users in the TOC were able to successfully monitor radio traffic and transmit on the VHF radio network to the radio operator in the field. The IP phone was successful with the IEEE 802.16, Sky Pilot, and ITT Mesh connections. Operators in the TOC were also able to communicate via an IP phone with the NPS operator using Desktop Communicator over the IEEE 802.16 network.

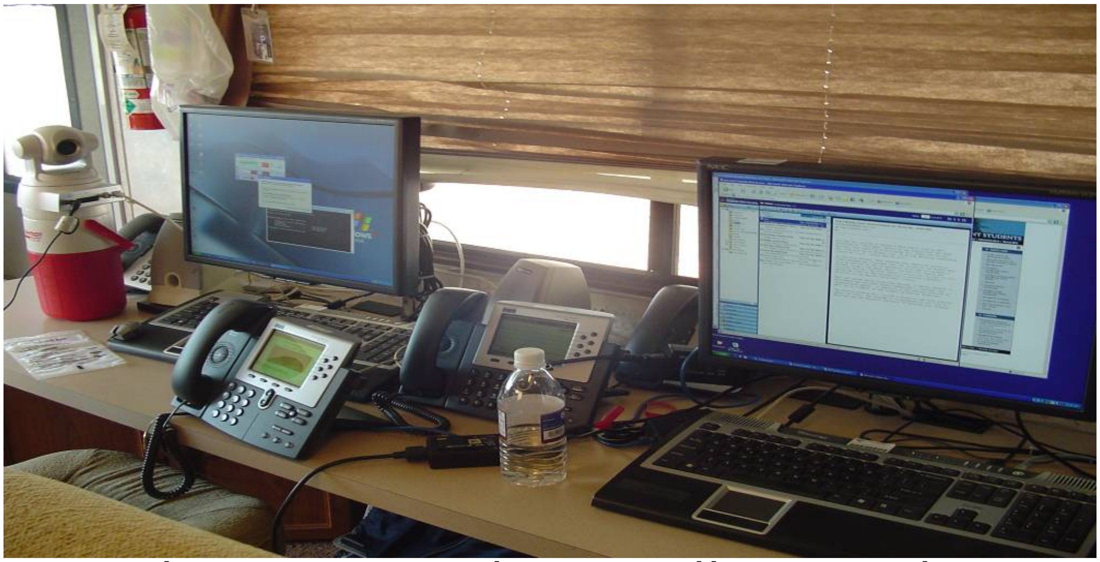

Figure 39. IP Phone to Radio Integration

Experiment four demonstrated integration of legacy military VHF/UHF radios into a mesh architecture and demonstrated the capability to pass voice traffic over a separate private network with the broader network using ITT Mesh as a backhaul instead of IEEE 802.16. This investigated using other waveforms to link radios into disparate networks within a larger network. The use of tethered balloons and UAVs were used to demonstrate a wireless network. RF converted into IP in this environment could bridge existing technologies with emerging mesh routing protocols to greatly expand communications.

This test demonstrated the successful integration of a mesh network for relaying voice traffic from a tactical radio. Desktop communicator was also successfully employed in a moving vehicle connected to a mesh network. A mesh device was added to a small helium balloon at a height of 1000 feet.

Figure 40. Balloon & MMR Mesh Node

A subscriber device was also added to a small Unmanned Aerial Vehicle (UAV). Other mesh devices in the mesh network included Inter-4 T-1.5 devices and the Inter-4 Mobile Mesh Router (MMR). The mesh network covered an area of approximately six square kilometers of Camp Roberts.

Figure 41. NPS Rascal UAV with Mesh Node

As with the previous experiments, a tactical radio was displaced beyond RF range of the TOC. From here, the tactical radio was connected to the NXU-2A and the Ethernet output of the NXU2-A was connected to another laptop. This laptop was configured as a join point with an

ITT mesh PCMCIA card connected to the mesh network. This configuration provided connectivity from the tactical radio network across the six kilometers of mesh enabled terrain to the TOC. A mobile radio operator was able to successfully communicate from a handheld VHF radio to the TOC and NPS operators. While connectivity over the mesh network was spotty at times, voice quality was excellent when the IP network was stable.

Figure 42. Author Communicating RF-to-IP via ITT Mesh

The join point laptop was loaded with the WAVE Desktop Communicator allowing an operator to use the Desktop Communicator to talk with personnel in the TOC and at NPS. This operator was also able to talk to the mobile radio operator using a hand held VHF radio. Voice quality was excellent and availability was dependent on the stability of the mesh environment.

b. Overall Experiment Conclusions

The result of these experiments demonstrated a unique capability not currently employed by the Marine Corps. The ability to network tactical radios into an IP network may provide a way for a DO platoon to communicate to multiple entities as required by their mission. Key milestones from these experiments were:

- Tactical Radios to multiple laptop communication
- Tactical Radios to CISCO-IP phone communication
- Tactical Radio to wireless device i.e. Palm Pilot
- Bridging different radio frequencies in order for separate radios to communicate via the network
- Ability to have multiply frequencies broadcast over one radio net
- Ability to bridge commercial radios to tactical radios via network
- Ability to use multicast and unicast communications
- Ability to network tactical radios across IEEE 802.16, IEEE 802.11A and Mesh network

These experiments demonstrate simple yet achievable changes to the current network architecture to help DO units communicate more effectively.

D. TECHNICAL CONSIDERATIONS

1. Security

Encryption of voice traffic is critically important in any mission oriented circuit. Encryption of voice traffic was handled in two ways during these experiments. All voice traffic is encrypted from radio to radio within the radio

network. This means that the voice traffic is encrypted from entry into the network and remains encrypted, in one form or the other, until it is accessed by the user on the distant end. From the radio operators location, voice is encrypted with standard military Type I encryption using Vinson keymat. This encrypted voice traffic is relayed over the RF connection to the base station radio where it is de-encrypted with the same keymat before being cabled to the NXU-2. The voice traffic is then changed to IP packets and sent over the IP network to the WAVE Server. This connection from the base station radio to the Wave Server is not encrypted and therefore problematic. There are three solutions to addressing this issue.

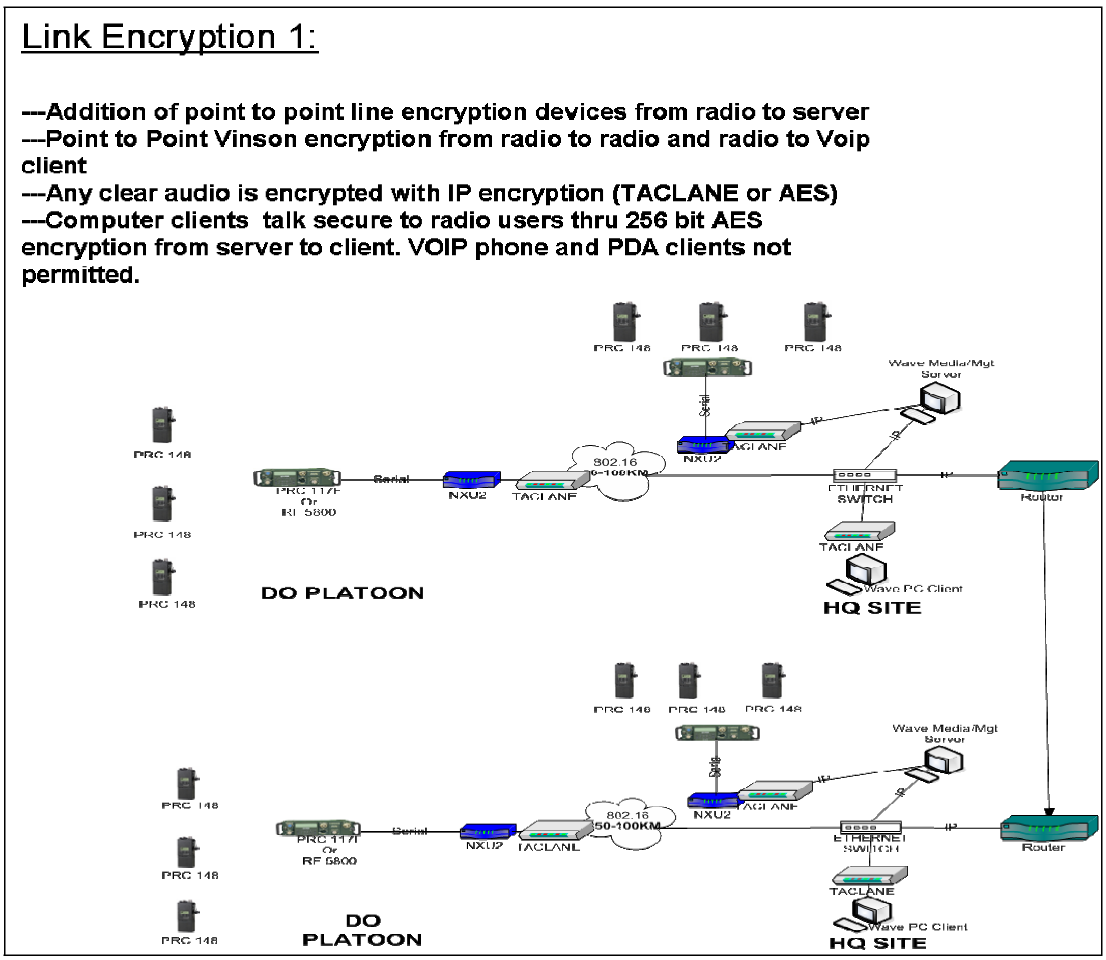

Diagram 8. Link Encryption Option One

Encryption option one (Diagram 8) requires the use of a line encryption device such as a KIV-7, OMNI-XI, or KG at the base station location. This line encryption device would be used to encrypt the traffic as it is transported over the long haul transmission media (IEEE 802.16, mesh, SATCOM, etc). Advantages include the assurance of a secure connection across the IP network. Disadvantages are the requirement for additional equipment and possible points of failure in the encryption devices. Also, IP phones and PDA clients could not be used in the option.

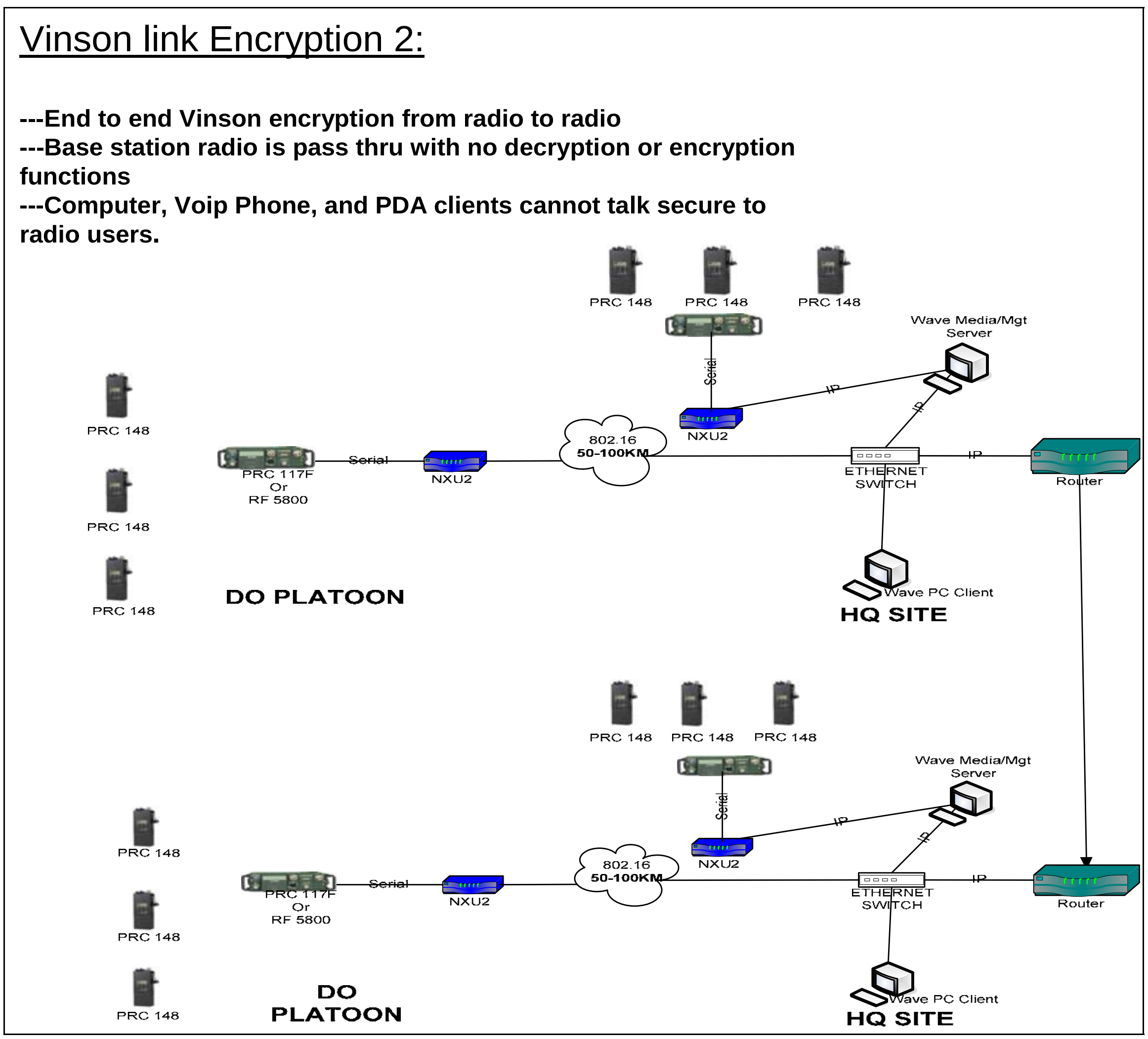

Diagram 9. End to End Audio Encryption Option Two

Encryption option two (Diagram 9) calls for the use of a pass-thru radio at the base station site. This radio does not de-encrypt the RF traffic it receives. It only sends encrypted RF audio traffic to the NXU for transport over the IP network. This solution does not require the use of a line encryption devices on the network since the voice is not decrypted until it reaches the distant end radio. The desktop, PDS, or IP phone clients will not work on the radio network for this configuration.

Once the voice traffic reaches the WAVE server it is encrypted via software. The WAVE server provides up to 256 AES encryption over the IP network to desktop communicator and IP phone endpoints. This encryption is not possible for POTS or cell phone users that access the voice network from the WAVE Server. Therefore, external encryption is required from the POTS or cell phone user by use of standard STE, STU, OMNI, etc. technology keyed to the same or encryption level as the radio network.

Advantages of option two include not requiring additional hardware encryption devices. The audio is encrypted during the entire transport over the IP network. However, the IP phone and PDA clients cannot be used since they do not have the built in ability to decrypt the audio from a radio.

Option three eliminates these line encryption problems by placing the equipment onto the SIPRNET. This network is authorized for the secret level of security on the voice network. Advantages of this option are the use of as little additional equipment as possible. This option also allows for the use of IP phones and PDA clients. This is the

recommended implementation since it requires the least amount of hardware and provides the most in capability.

SIPRNET 3:

---Use SIPRNET as the IP network
---Radio audio is decrypted at the radio site and transported in the clear across the IP network
---Radio traffic line encryption devices are not required
---Server to client IP connections are encrypted with 256 bit AES encryption across the SIPRNET

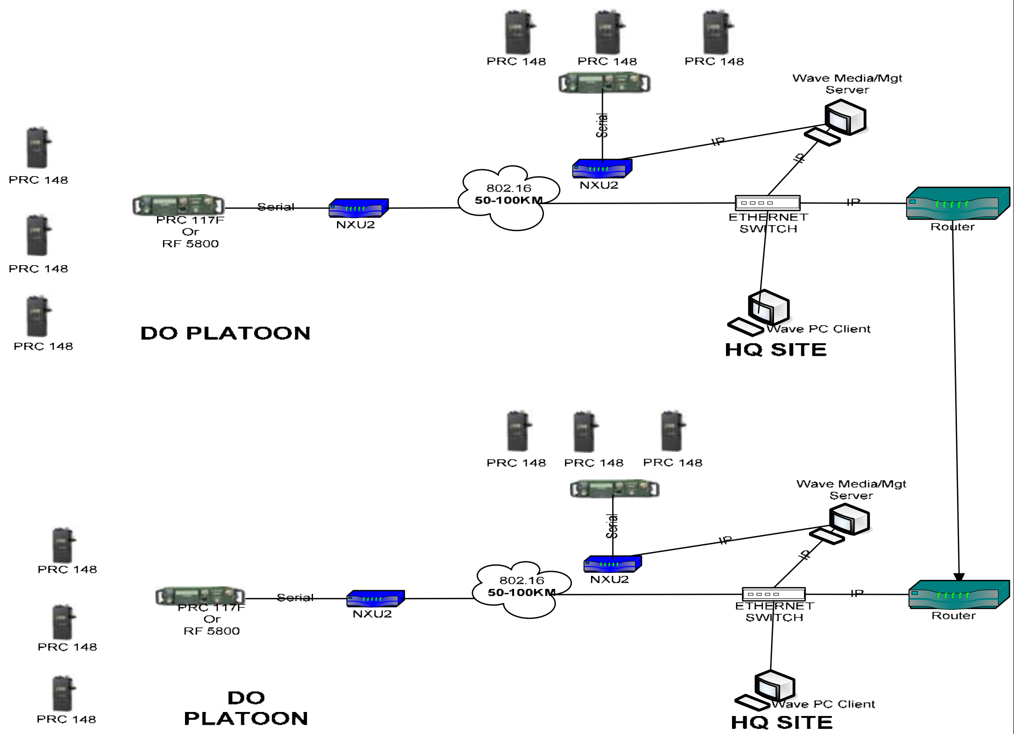

Diagram 10. SIPRNET Encryption Option Three

2. Bandwidth/Throughput Measurements

The affect WAVE technology has on IP networks is important. The authors decided to conduct measurements of bandwidth utilization in a lab setting rather than the field. The purpose is to investigate the impact the technology has on an IP network. The authors were limited in equipment and network devices, therefore only a few devices were enabled for measure and analysis. The authors

believe the data obtained for measure is scalable for larger networks depending on the number of clients using the WAVE software. The numbers of radio networks bridged into the IP network are only limited by the number of NXU2s and radio nets.

Figure 43. Lab Test of Bandwidth/Throughput

The authors used the *Solar Winds*™ network management tool to measure network performance. In order for measurements to be obtained, network devices were SNMP enabled. "The *Simple Network Management Protocol (SNMP)* is an application layer protocol that facilitates the exchange of management information between network devices. It is part of the Transmission Control Protocol/Internet Protocol (TCP/IP) protocol suite. SNMP enables network administrators to manage network performance, find and solve network problems, and plan for network growth."[25] Solar Winds measurements were primarily done on the WAVE server and one client running WAVE Desktop Communicator.

[25] CISCO Corporation Website.

One PRC-117F was configured to receive the maritime weather frequency. The purpose of selecting this frequency is to provide the network constant and continuous radio communications over a continuous period. A client running Desktop communicator was configured to receive the audio. Since the client was only receiving and not transmitting audio, the authors realize the data only represents receive traffic. The intent was to show the impact of the technology on network load in general terms. The size and scope of the IP network will greatly determine the actual effect of the technology as a whole.

The SNMP function of the tested NXU2 was not enabled by the vendor; therefore bandwidth could not be measured directly. The NXU2 was configured for a 13Kbps codec which is the lowest setting allowed by the system. Since all traffic must flow through the WAVE server, the bandwidth/throughput measurements were taken primarily from it and a client running on the network.

Wave server and client measurements listed in Table 4 reflect a snapshot of data recorded over a 24 hour period. The primary intent was to determine the effect the WAVE server and client applications had on the network. Bandwidth was scaled to 256Kbps and 1MBps. Currently the Marine Corps has very limited bandwidth at the battalion level. The authors believed 256Kbps was a conservative throughput baseline for this test. The 1MBps figure reflects the amount of bandwidth that could be provided by an IEEE 802.16 link or other transmission media.

DEVICES	WAVE CODEC	NXU2 CODEC	NO ENCRYPT	256bit ENCRYPT	RX AVG @ 256Kbps BW	TX AVG @ 256Kbps BW	RX % UTIL @ 256Kbps BW	TX % UTIL @ 256Kbps BW	RX AVG @ 1MB BW	TX AVG @ 1MB BW	RX % UTIL @ 1MB BW	TX % UTIL @ 1MB BW
SER ONLY	16Kbps	13Kbps			2884bps	478bps	1.99%	0.33%	2884bps	478bps	0.33%	0.06%
SER & 1 CLT	16Kbps	13Kbps	X		143K	90K	39.85%	25%	144K	92K	17.09%	10.88%
SER & 1 CLT	64Kbps	13Kbps	X		192K	113K	86.38%	62%	206K	146K	20.62%	13.52%
SER & 1 CLT	16Kbps	13Kbps		X	180K	115K	70.30%	44.91%	183K	118K	18.42%	11.78%
SER & 1 CLT	64Kbps	13Kbps		X	235K	167K	72.77%	47.29%	210K	149K	21.55%	15.30%
CLIENT (1)	16Kbps	13Kbps	X		104K	449bps	39%	0.26%	92K	426bps	9.46%	0.05%
CLIENT (1)	64Kbps	13Kbps	X		156K	765bps	59%	0.03%	167K	832bps	16.00%	0.08%
CLIENT (1)	16Kbps	13Kbps		X	118K	597bps	46.11%	0.23%	118K	596bps	11.79%	0.13%
CLIENT (1)	64Kbps	13Kbps		X	172K	835bps	67.69%	0.31%	124K	620bps	12.37%	0.06%

Table 4. Server & Client Bandwidth Measurements

The table illustrates the effects of various codecs and the use of encryption on bandwidth. There are multiple combinations of settings on the WAVE server and the authors chose the highest and lowest server codec. Predictably an increase in codec or application of encryption increases the amount of bandwidth used. Of note, the WAVE server has little impact on the overall bandwidth.

The authors believe that any adoption of WAVE technology for DO should closely parallel increases in bandwidth capacity for the Marine Corps infantry battalions or those entities directly supporting DO units. Adding RF voice communications on current data networks would only increase bandwidth needs and compete with other applications residing on the network. Since the authors did not apply this test to an actual military network the exact impact is estimated.

E. INTEGRATION OF RF-TO-IP TECHNOLOGY WITHIN THE MARINE CORPS

1. Location of Wave Server within the Marine Corps

The Wave Server could support a MAGTF in various configurations. The largest configuration would be an enterprise implementation configured and operated at the

MEF level. The smallest implementation would be the use of the WAVE Management and Media Servers loaded on a single laptop supporting a Battalion COC. Implementation at the MEF level would take considerable configuration depending on the number of channels required and the number of users supported. The MEF implementation, while possible, is not recommended to support battalion level voice operations. By providing the server configuration and control at the Battalion level, faster coordination and troubleshooting are likely. Also, if the server is located at the MEF level, all radio traffic must traverse the entire IP network up to the MEF level in order to be processed and returned to the Battalion VOIP user. A multicast implementation would have much less of an impact on the network as opposed to numerous unicast connections. The Battalion level server administrator also has the ability to provide access to any higher command user if requested. Therefore, all assets within the MAGTF can have access to voice traffic as requested with the central configuration coming from the unit most connected with the radio networks in question.

2. Management of Voice Network

The management of the voice network becomes the responsibility of the unit controlling the server. Once the voice network is converged onto the IP network, various configurations, accesses levels, and permissions are possible for users. The server administrator can provide a monitor only account to users that will disable the ability to transmit on the radio network. This tool is useful when a section only requires situational awareness of a unit rather than the ability to provide command and control. Users can also be granted the ability to monitor or

transmit on IP telephones, POTS phones, or even cell phones. Certain security measures have to be in place on these type of accesses to ensure sensitive information being transmitted on a radio network is not relayed to a non-secure phone line. These measures are addressed elsewhere in this document. Traditional voice encryption techniques for phone systems can mitigate this risk and still provide the service to users. Users on a personal computer, such as those in a command center, can also be granted a channel for text chat and audio monitoring without the ability to transmit on the radio channel. This function provides the ability for users on the IP side of the network to collaborate via voice or text traffic instantly without having to use a separate phone line.

IV. DO COMMAND AND CONTROL CONSIDERATIONS

A. EXTERNAL FACTORS

The current Marine Corps communications architecture provides a proven yet limited networking capacity. For example, a Marine Expeditionary Force (MEF) level command element (CE) is doctrinally provided with a Ground Mobile Forces (GMF) satellite connection of 1024 Kbps of networking bandwidth.[26] This bandwidth is further extended to the Division, Marine Logistics Group (MLG), and Air Wing. Of this 1024 Kbps of aggregate bandwidth distributed from the MEF, it is further allocated into respective individual networks. A common allocation of this bandwidth includes NIPRNET (128 Kbps), SIPRNET (256 Kbps), VTC (386 Kbps), and a Digital Trunk Group (128 Kbps).[27] There are organic assets available to augment the networking bandwidth for the MEF to include using additional GMF terminals normally slated for use by subordinate units such as the Wing, FSSG, or Division. It is not uncommon to see a MEF augmented with an additional Defense Information Systems Network (DISN) satellite Standard Tactical Entry Point (STEP) satellite connection. With both satellite links, the MEF is still only supplied with roughly the equivalent of two T-1 lines worth of bandwidth for non-intelligence based communications networking.

[26] TM 083447A/08348-10/1 GMF Satellite Communications System.

[27] TM 08658A-14/1, AN/TRC-170 (V) 5083447A/08348-10/1 GMF Satellite Communications.

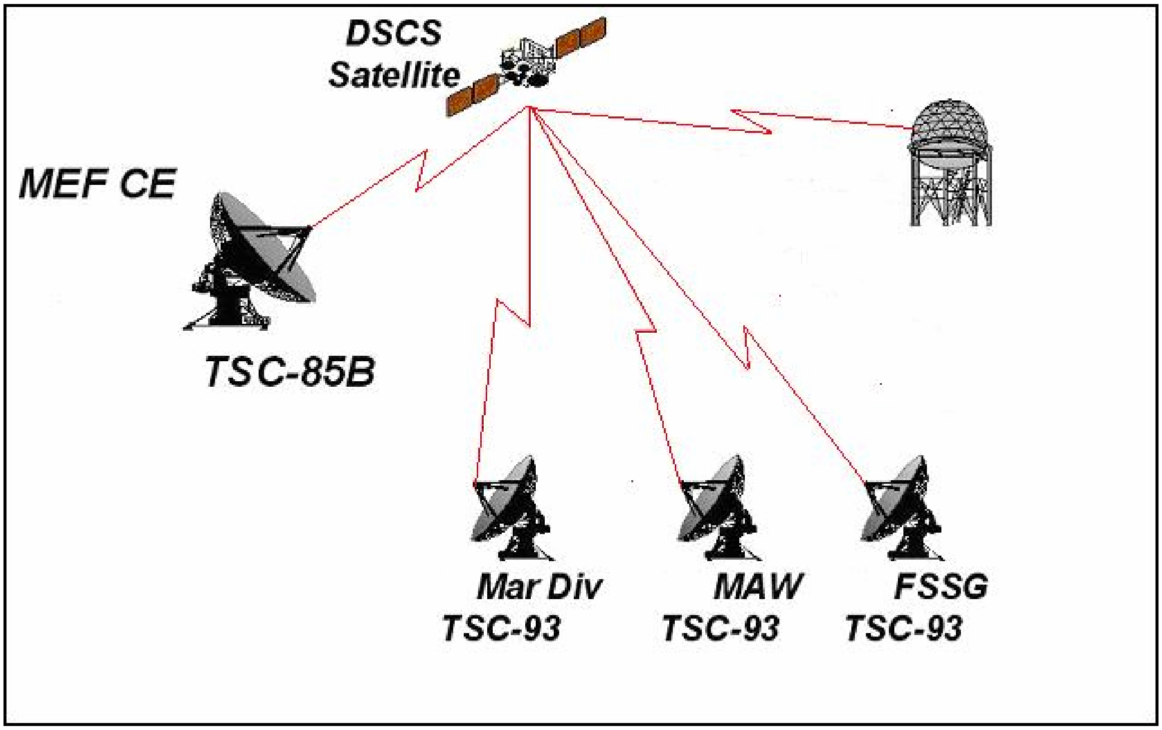

Figure 44. USMC Ground Mobile Forces SATCOM

The recent development of converging technologies from a circuit switched network to an Internet Protocol (IP) based network presents many challenges to the Marine Corps limited available tactical bandwidth. While the proliferation of IP based communications provide for many new capabilities to include common user protocols, open systems architectures, common transmission media, and others, the cost to the user is the need for additional bandwidth. This bandwidth constraint will be relieved as the advent of Transformational Communications Satellite (TSAT), the Global Information Grid (GIG), and Joint Tactical Radio Systems (JTRS) begin to evolve and become fielded in the near future. Until then, intelligent and inventive use of the networks we have available is the way ahead to transformation.

The Distributed Operations Concept is an instance of an immediate need for the Marine Corps to begin a smart use of available networking bandwidth. As evidenced by recent evaluations of the Distributed Operations Concept, long range and extended operations translate into additional weight carried by the already belabored Marine. Rather than increase the equipment burden on these Marines, not to mention the additional non war-fighting skills required to operate such equipment, the Marine Corps has to find ways to pull these Marines into the network with minimal impact on the Marine and minimal impact on the bandwidth constrained network.

As for the position of the DO platoon in this hierarchy of networking bandwidth, they are further handicapped. The DO platoon is the most bandwidth constrained of all, with access to bandwidth available only through organic tactical radios and Iridium based handsets. The highest useable bandwidth for data transfers is an average of 40 Kbps. If this bandwidth is not constrained enough, this 40 Kbps is on the bottom tier of the network. So, if a DO platoon had the requirement to send data outside of the MEF’s immediate area of operation (AO), it would have to contend with the connectivity, availability, robustness, and capacity of all layers between their location and the MEF satellite connection. Their alternative is the Ultra High Frequency (UHF) satellite connection from a man-portable AN/PRC-117 radio. While certainly capable 40 Kbps data transfer, the saturation of available UHF satellite channels would not realistically support the impending mission of the DO platoon without dedicated assignment of UHF satellite access.

1. Bandwidth Limitations Considerations

The limited bandwidth available to the MEF is further constrained for subordinate users. Traditionally, the MEF extends its networks to Major Subordinate Commands (MSC) via point-to-point GMF satellite links from an AN/TSC-93 or tactical microwave connections from the AN/TRC-170. The AN/TSC-93 provides a connection to the MEF up to a rate of 2048 Kbps.[28] The AN/TRC-170 provides this connection terrestrially at rates up to 4098 Kbps. Any connections below the MSC level will be connected to the network via the smaller terrestrial microwave terminal known as the AN/MRC-142. The AN/MRC-142 provides data rates up to 576 Kbps.[29] Important to note is the fact that all of these subordinate connections are sharing the MEF's one to two T-1 equivalent connections out to the GIG.

2. Possible Solutions

Possible solutions for mitigating this communications deficit include the use of a "disassociated processing of command and control", or the inclusion of additional networking equipment. Both have costs associated with them that must be considered in lieu of the mission. The basic hurdles of communications are tied to our current knowledge of physics and technology. These limits identify themselves in the current equipment and technologies available for fielding. Among others, these hurdles of physics materialize into communications link budgets for increasing power, bandwidth, and antenna size for communications transmission equipment. The technological limitations of commercial-off-the-shelf (COTS) equipment is promising yet limited in its capabilities. Understanding these

[28] CJCSM 6231.04 Joint Transmission Systems.

[29] TM 09543A-12: AN/MRC-142 Radio Terminal Set.

limitations for the effective employment of command and control at the tactical level is critical in providing a realistic and immediately attainable solution.

a. Option 1

This option is demonstrated by processing of information at an intermediate headquarters level. This level could be the Landing Force Operations Center (LFOC), MEF Command Element, Division Command Post, or Company Command Post. The level of command and control (C2) is mission dependent and not critical for this C2 analysis. The critical piece to the disassociated processing is the location of the manpower intensive data processing and intelligence analysis. The key for support is on the efforts of higher headquarters supporting the DO Marine element. The information is processed and staffed at the headquarters level and passed on to the DO Marine via the IP enabled voice network. All intelligence gathering, fire support processing, data processing, logistics coordination and more are done at a higher headquarters element. The required communications bandwidth, equipment, batteries, training, etc. needed to conduct these missions would no longer be required of the DO platoon. The enabling factor allowing this concept lies in the networking of the organic voice assets to which the DO Marines are already well versed. In lieu of the critical bandwidth deficiencies faced by the DO Marine, voice communications would be used to connect the DO Marine to his requirements. As intelligence, logistics, fire support, and information become available to higher headquarters, it is processed and relayed to the DO Marine over the IP enabled voice network.

The equipment costs associated with this option are lowest of the two but the human costs are higher. The human costs would be associated with the additional manpower required to support the forward deployed DO Marine from the headquarters staff. Additional manpower would also be required to provide the enhanced voice communications relay supporting the additional distance of the DO platoon. A dedicated communications support element, commonly known as the radio retransmission team, would be required to close the additional distance for the communications link. This team could be as small as a two or three man element with specialized training on the proposed equipment composition. Their primary mission would be to locate an attractive communications relay point within the radio frequency (RF) range of the DO platoon. Once established, this team would provide an aggregated and networked relay of the High Frequency (HF), Very High Frequency (VHF), and Ultra High Frequency (UHF) communications from the DO platoon.

b. Option 2

This option requires the use of available COTS wireless equipment to be employed as a radio retransmission location in support of the DO platoon at their mission location. The proliferation of small, lightweight, high capacity, reliable, secure long-haul communications systems available on the market today, allow for a multitude of options for this long haul connection back to the higher headquarters. The proposed implementation also provides the ability to allow different frequency voice networks to interoperate. Voice traffic on one network, a UHF ground to air close air support mission for instance, would be transparently available to other VHF ground users as well

as any IP networked user in the chain of command. Users higher in the chain of command would also have the option of transmitting on the HF, VHF, or UHF voice networks of the DO platoon from applications running on laptops or IP phones in their command centers.

Commanders at any level have the ability to monitor or control the DO force remotely. The enabling technology for this implementation uses currently available commercial grade software and hardware. The encrypted voice traffic from the DO platoon radios is converted to IP packets and sent over the network to a common server used for mixing and assigning access to the voice channels. The DO voice net can be accessed via IP phones, cell phone, POTS phones, Personal Digital Assistant (PDA), or a laptop computer from anywhere in the world to which the IP network extends.

3. External Factor Analysis

In conclusion, the limited bandwidth available to tactical units is hierarchical in nature and decreases the closer you get to the tactical edge. The one or two T-1 equivalents of bandwidth provided by the MEF Command Element drastically limits the network services that can be provided to an infantry battalion that requires access to distant units over an IP infrastructure. While terrestrial solutions may provide sufficient sized connections to adjacent units, the joint environment operated in today often requires satellite connections to higher commands. These satellite connections are strictly limited in bandwidth and therefore all network services have to be limited in their usage of the precious resource. This paper illustrates the convergence of typical voice radio networks

onto the IP infrastructure. Once the voice network is accessible over all levels of command and control of the force, numerous options are available for supporting the most forward deployed Marine on the battlefield. Rather than burdening the Marine with additional equipment for supporting his C2 needs, the intelligence gathering, logistics control, and other requirements can be relegated to a higher command element on the network to process. Once processed, the information can be passed with the converged voice network to the forward deployed Marine. The supported Marine becomes lighter, smaller, faster, and smarter with the same equipment he has carried and trained with for decades.

4. Employment of Network Nodes

The ability to establish network nodes to properly network voice communications is important to consider. The questions of responsibility of such nodes should be investigated. Given the current T/O structure of the Marine Corps the authors have concluded Distributed Operations should in most cases, employ network nodes at the closest exchange server location within the organization. In most cases this would be the battalion command post but could reside at the regimental or division level of the organization. This is not to say a DO unit must enter the network at a given echelon but this is the most likely scenario for DO.

From the DO platoon perspective, RF-to-IP node integration would occur where habitual relationships are already formed. In most cases this would be the battalion communications platoon. The communications platoon would bear the responsibility of ensuring all channels were

configured as required. Prior to mission launch detailed communications planning would be required to determine the best method of bridging into the IP network infrastructure. DO mission planning may have to include additional attachments whose primary mission is to establish and maintain long-haul communications with the IP network.

5. Power Considerations

The authors believe a mobile platform is most desirable for establishing long-haul communications. Whether a DO platoon employs IEEE 802.16 technology, SATCOM or Mesh, the ability to have a stable platform where power generation is reliable and continuous is most desirable. As of the date of this research MCWL has expressed the desire to keep Distributed Operations vehicular independent but have not ruled it out.

In February 2006 one of the authors of this thesis attended a DO logistics conference in Quantico Virginia. Combat Service Support (CSS) for DO does raise serious concerns about how self sustaining a DO platoon can or must be in order for mission success. As the date of this research several areas of research had been identified for study. The conference generated serious discussion about power required for DO. In the short term, DO must use the technology available today. A mobile communications platform would greatly increase the effectiveness of a DO Platoons ability to communicate. From this platform, the DO units could recharge batteries and employ more powerful communications assets as needed. The technology in this thesis could easily be adapted to fit into a mobile platform.

6. Concept of Operations

The main purpose of this section is to examine the advantages and disadvantages of possible network architecture scenarios for DO. In each scenario the integration of legacy radio systems with an established IP network is the baseline. The use of four different long-haul links is used to show how each network topology would unfold. In all cases the intent to maximize the number of users (units). The ability for DO to have constant and continuous communications is vital to its mission. Therefore it is assumed that all entities have access to and are fully integrated into the larger IP network infrastructure.

a. Overview

The DO platoon must have a reliable reach back capability in order to facilitate its communication requirements. Diagram 8 details in broad terms what the logical network topology could look like. Each unit in the IP network is only logically connected. Some units may be several miles from each other but still are connected via the network. The diagram indicates DO platoon merely establishes a connection into the larger IP network. In this case four different connections are considered. IEEE 802.16, UHFSATCOM/VHF retransmission, Iridium SATCOM and Mesh are all considered for the long-haul communications bridge for DO. Each scenario uses Twisted Pair WAVE to bridge legacy voice communications to multiple clients/units on the network. Each unit then could run WAVE Desktop communicator application to speak directly to the DO platoon via the long-haul link.

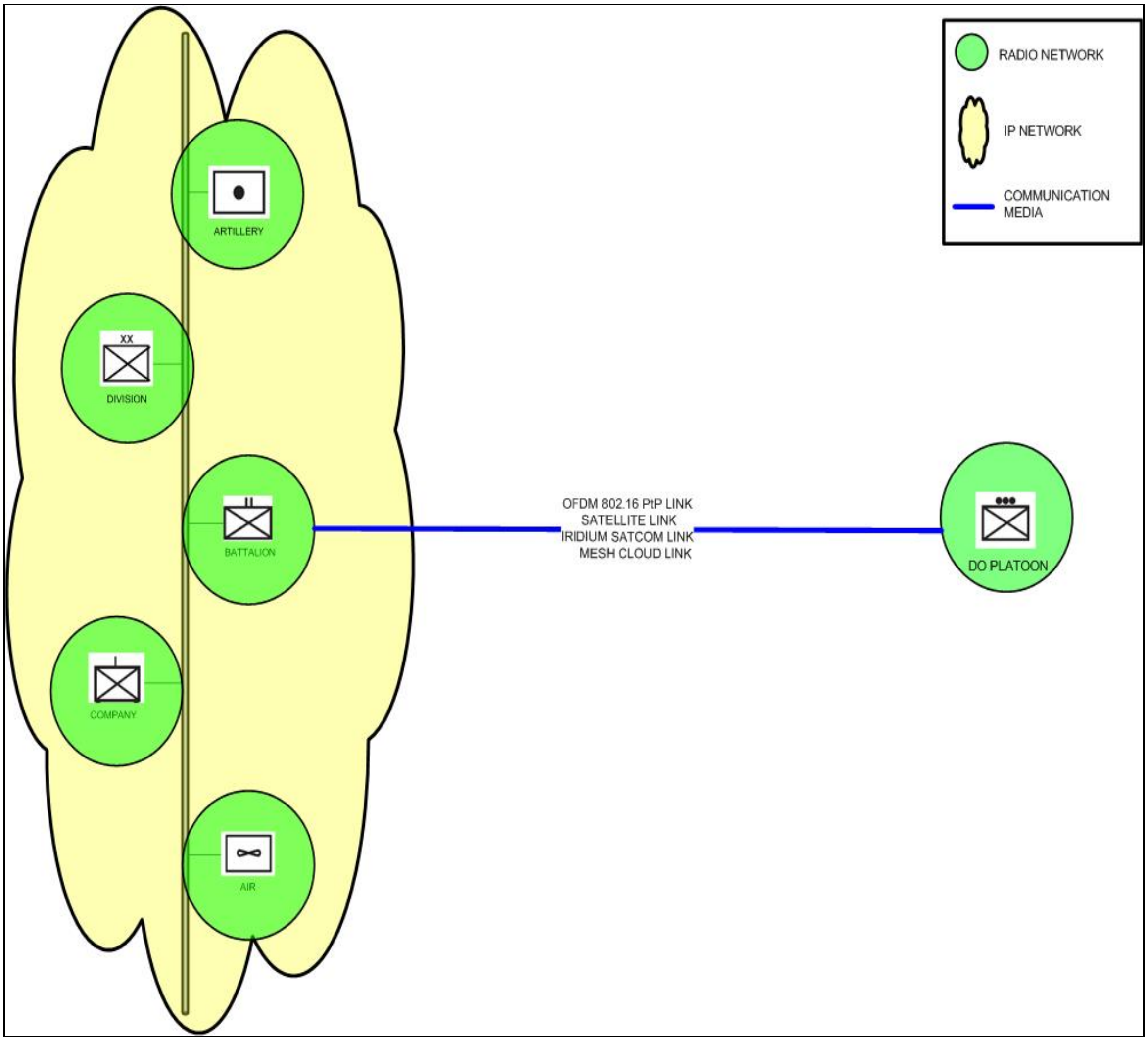

Diagram 11. Concept of Operations – Overview

All scenarios use existing legacy equipment to facilitate communications and introduce new technology to fill the gaps in the existing communications suite. Each scenario approaches this challenge from the platoon perspective and the network perspective, thereby tying in those entities that will support the DO mission. In this case the DO platoon will rely mainly on its parent infantry battalion to provide the network node interface and server

management. The authors believe this would be a reasonable assumption based on the current T/O of the Marine Corps.

b. Scenario One

Diagram 9 uses IEEE 802.16 technology to facilitate PtP long-haul communications into the network. Each user runs WAVE Desktop communicator for voice communications. The WAVE server resides at the next higher echelon. The NXU2 and legacy radio does not need to reside where the server is but merely be connected to the network. In this scenario the NXU2 and PRC-117F VHF radio is located with the IEEE 802.16 link. As long as the connection is maintained with the IEEE 802.16 radio, the DO platoon is free to maneuver about their battlespace within the max range of their VHF assets. If the DO platoon moves outside the VHF range, then the signal is lost and communications are lost to higher or supporting echelons. If the IEEE 802.16 link is lost, the DO Platoon maintains internal VHF voice communications as long as they do not exceed this range.

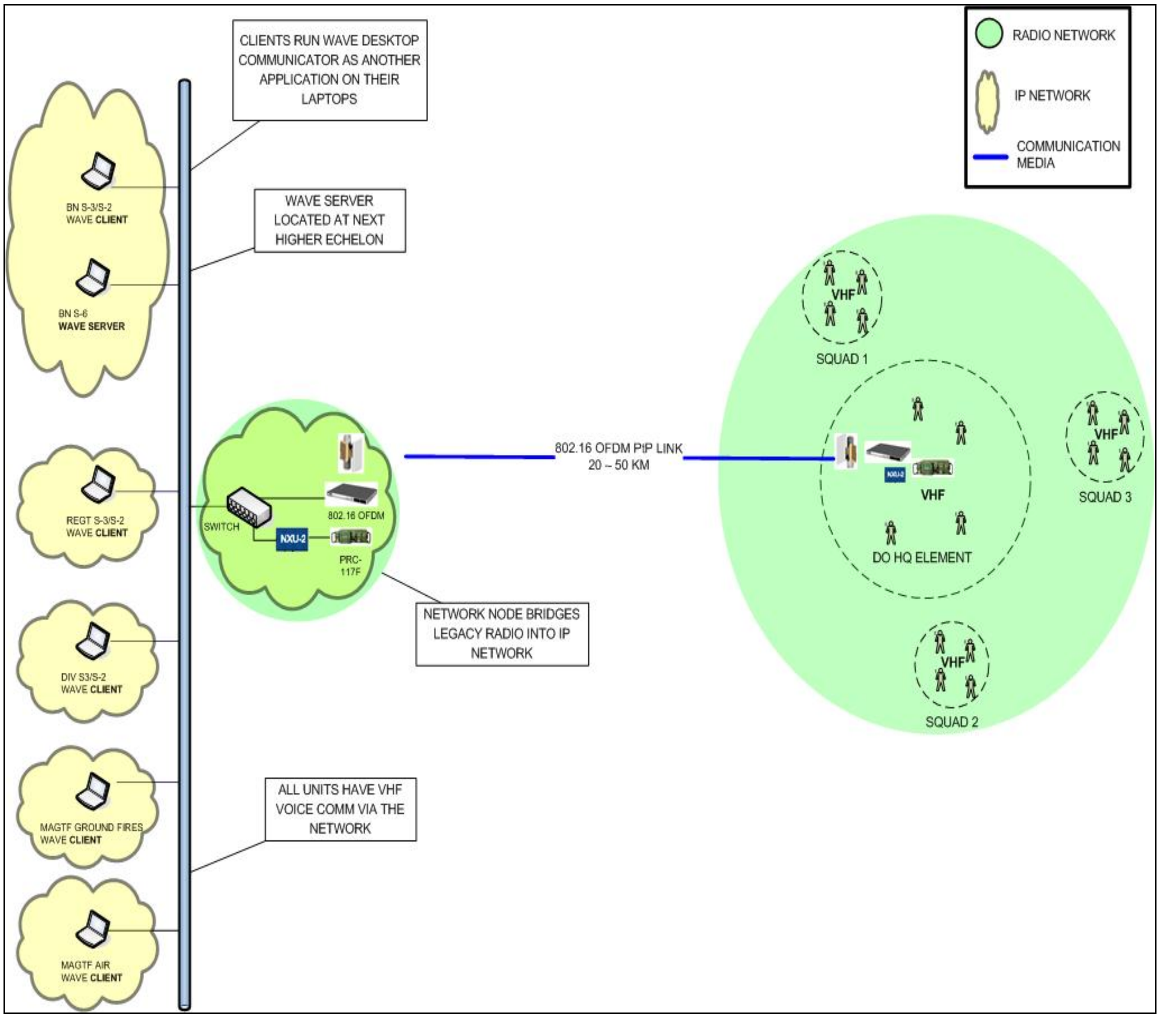

Diagram 12. IEEE 802.16 Link into the Network

Advantages:

- The DO platoon can maintain internal communications if the IEEE 802.16 link is lost. Thus alternate means of communications could be established to higher, such as UHF SATCOM.
- The DO platoon can speak directly to multiple units at the same time. Each supporting unit would have real time collaboration of voice communications.
- Clients/Units can have duel use of existing computer assets since each laptop running Wave

Desktop communicator could be used for other purposes as well. For example Radio Operators could monitor network traffic while updating a unit data base.

- Intelligence from multiple sources could be directly communicated from S-2 representatives to the DO platoon. Any qualified individual could merely key the radio on their computer to speak to the DO Platoon.
- Call for fires for artillery and air support could be facilitated from the gun-line directly to the platoon. De-confliction of fires can be done while the Fire Support Coordinator (FSC) is monitoring voice communications via the network.
- Communications are transparent to the individual DO platoon member. Little or no additional radio configuration is required.

Disadvantages:

- If the IEEE 802.16 link is lost then communications are lost outside of the platoon
- Establishing and maintaining an IEEE 802.16 link is terrain dependant. This link must be PtP for extended distances. The DO platoon need not be physically located with the IEEE 802.16 radio but must not exceed the VHF range of the PRC-117f radio connected to the NXU2 and the IEEE 802.16 radio. Additionally it is unlikely the DO headquarters would leave important communications unattended therefore some size element would have to be stood up to guard the network node. This would either come from the supporting higher unit or the DO platoon itself.
- The IEEE 802.16 link is a single point of failure and is subject to enemy fires or exploitation if discovered.
- Any network node would require additional power consumption. Any network nodes in the field would have to be adapted to external battery resources.

- The IEEE 802.16 link does have range limitations necessitating the need for detailed communications planning and detailed link budget analysis.

c. Scenario Two

Diagram 10 integrates existing capabilities of the legacy radios carried by the DO platoon and network node integration. Here the DO platoon uses existing VHF/UHF assets to communicate to higher. The use of retransmission blends the VHF signal with a UHF SATCOM signal. The DO platoon can continue to use their VHF assets internal to the platoon while one radio acts a retransmission node to carry the blended signal over a 25 KHz SATCOM link back to higher. There the signal is converted back to VHF and linked into the NXU2 where the signal is digitally sampled and put into IP form. The WAVE software then connects all entities as required.

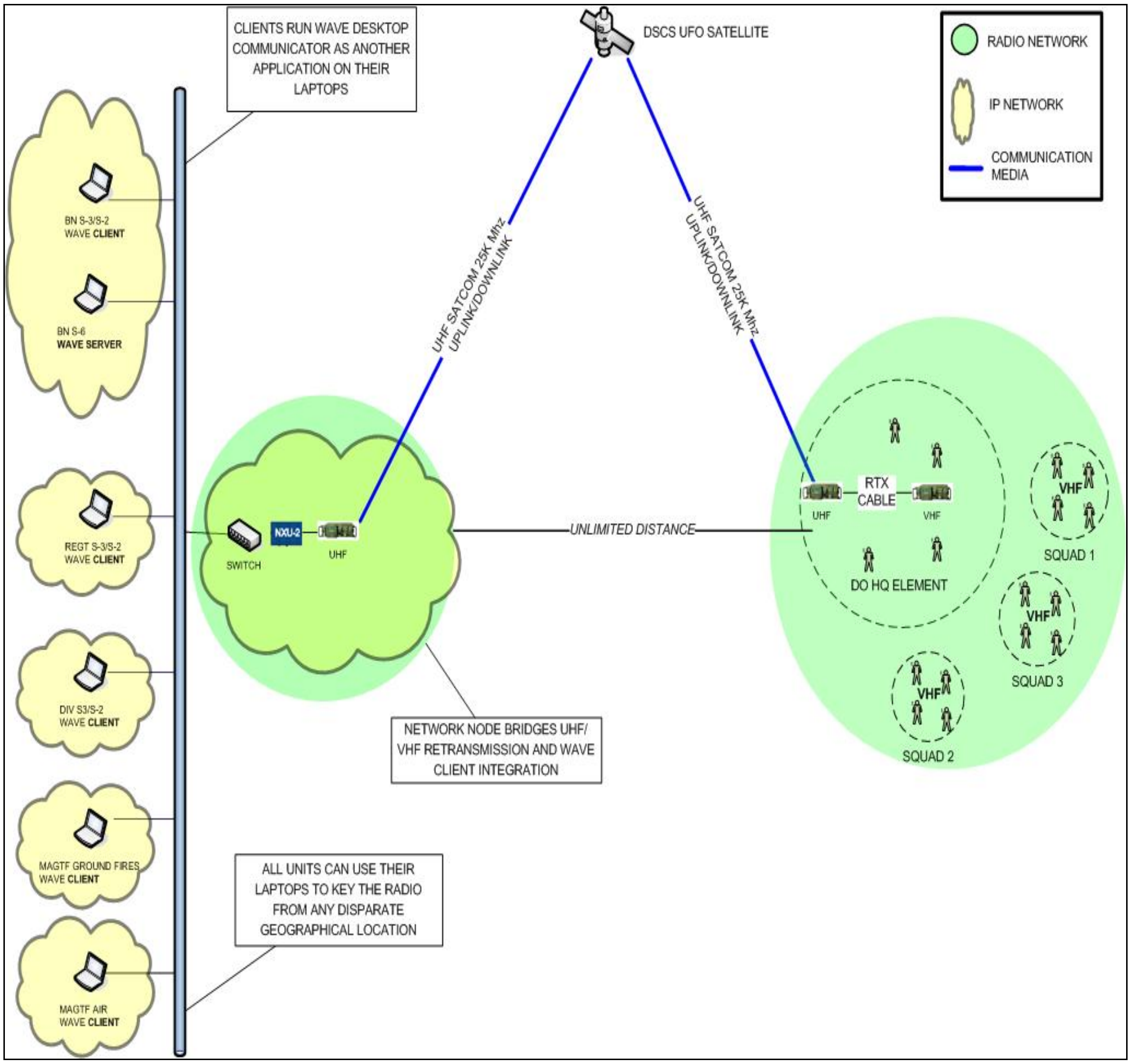

Diagram 13. VHF/UHF SATCOM Retransmission into IP Network Node.

Advantages:

- Only additional equipment required is the appropriate retransmission cable for the PRC-117F
- Worldwide communications for DO platoon
- DO platoon maintains its maneuverability within the VHF radio sphere.

- Additional PRC-117 may have to be carried for this mission, adding to the weight the existing combat load.

Disadvantages:

- 25 KHz channel availability may not be available to support DO operations. In most cases there is limited capacity for dedicated SATCOM channels.
- Mobility of the DO headquarters (HQ) element may be hampered by maintaining static network node in the field.
- Additional training required for retransmission operations.

d. Scenario Three

Diagram 11 uses the ETCS system has main long haul link. The audio port from the ETCS is connected to the NXU2 then bridged into the IP network. The 2,400 Bps bandwidth of ETCS does not become a limiting factor due to the transport of the raw audio from the iridium handset over the network. The handset is not used as a transporter of data. The voice traffic from the audio pins of the iridium handset are converted to IP packets in the same way as it is done in the tactical radios. DO platoon could then maneuver uninhibited through out the battlespace while all supporting entities would be connected via the network.

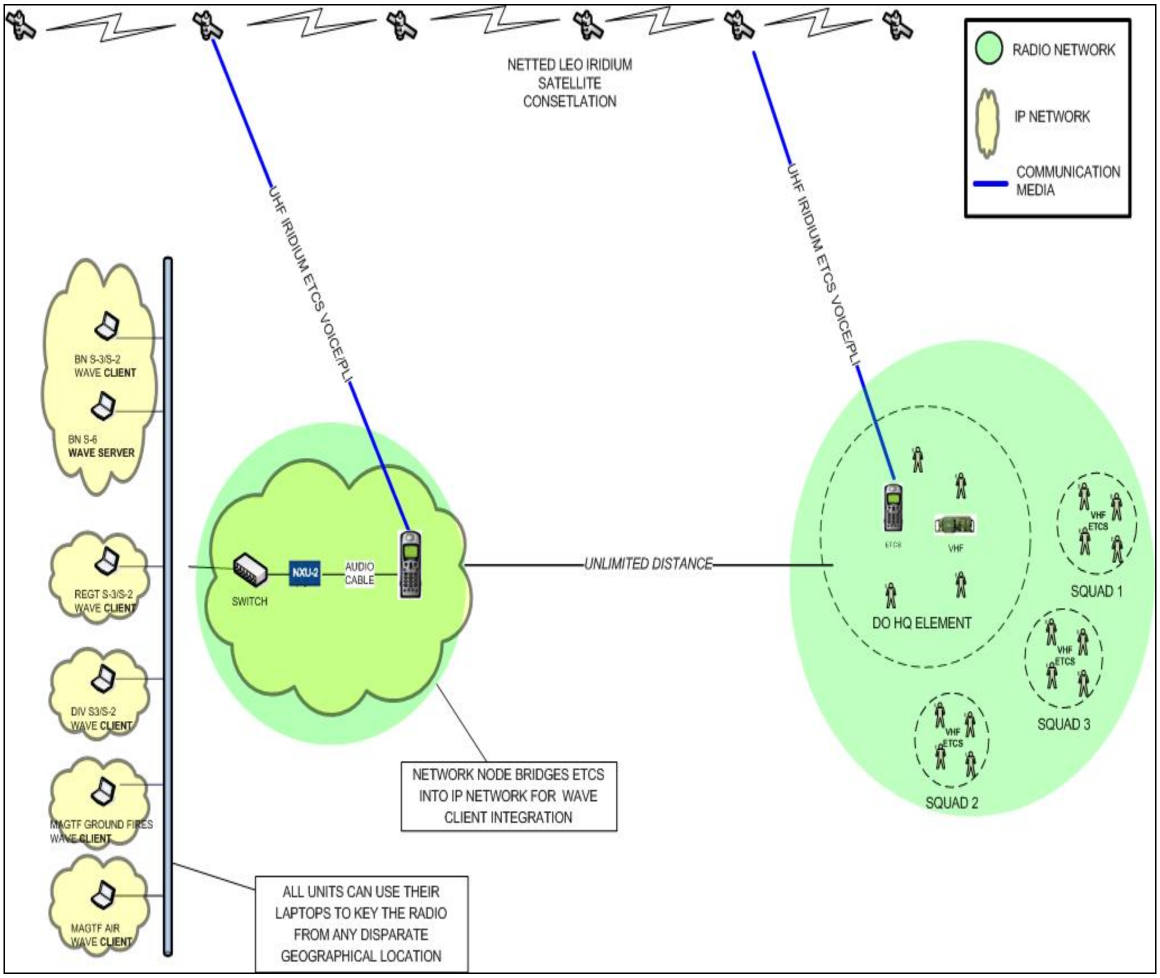

Diagram 14. ETCS Linked into Network Node

Advantages:

- Continuous satellite connectivity for the DO platoon. Worldwide coverage in most cases.
- No additional equipment required. Entities are bridged via the network
- Continuous voice communications
- Allows entities without ETCS to communicate to DO platoon.

Disadvantages:

- ETCS system is not reliable in rolling and steep terrain therefore complicating voice communications at the network level.
- Limited mobility due to possible signal loss of ETCS system. Because the system is SATCOM dependant, cover and concealment is jeopardized at the expense of continuous communications.

e. Scenario Four

This scenario uses mesh enabled equipment and legacy radio systems over a common mesh network. The DO platoon can maintain connectivity over a variety of methods. Diagram 12 depicts several network nodes that extend the network of the platoon. The use of UAVs, balloons or PtP links work together to provide coverage for the DO platoon. Here the VHF legacy assets connect to a NXU2. From there the NXU2 is connected to the mesh infrastructure via wireless mesh bridge. The mesh infrastructure is connected to the IP network where this information is extended to all clients/units as needed via WAVE.

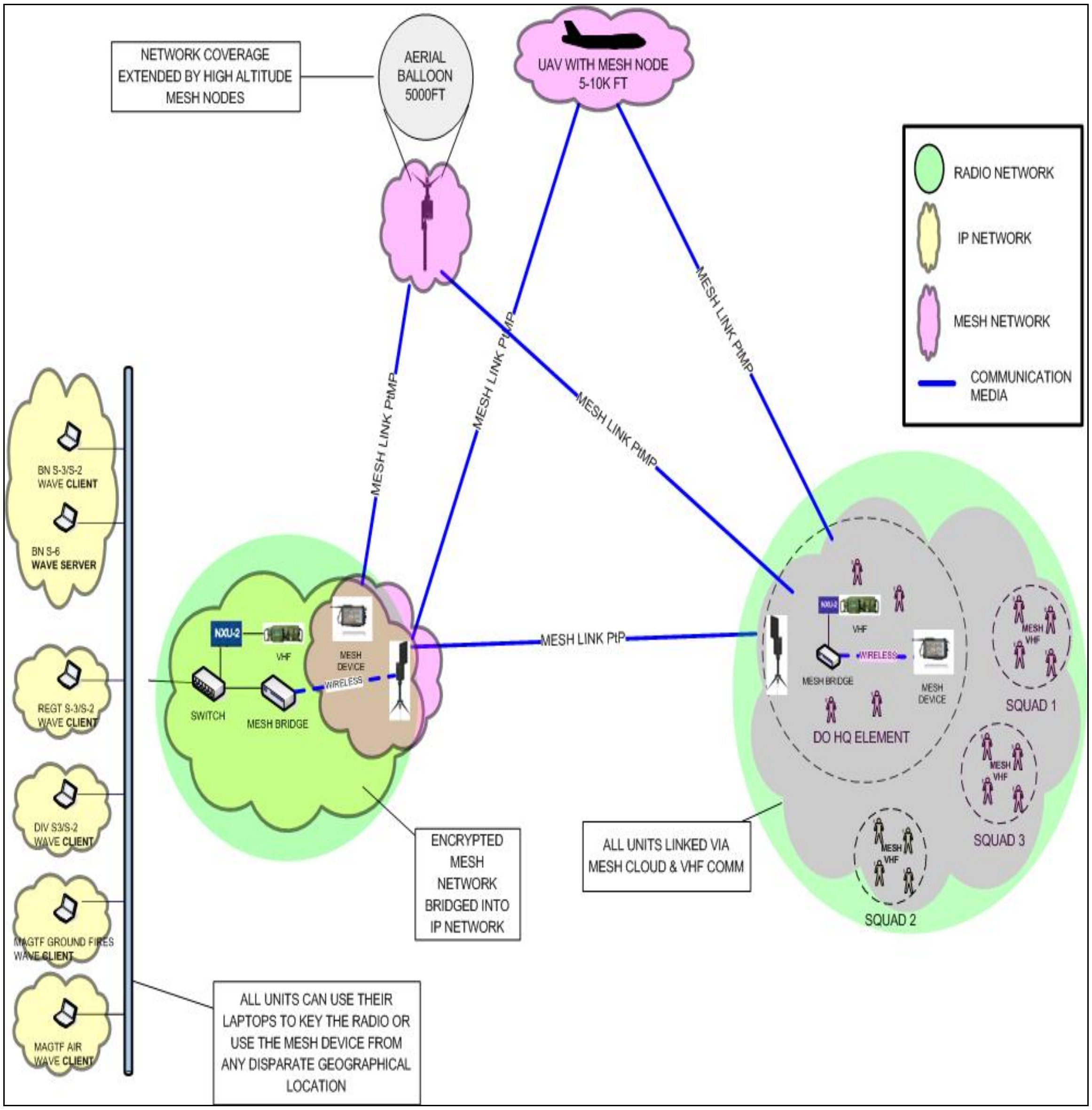

Diagram 15. VHF and Mesh Equipment Bridged into IP network via Mesh Cloud

DO platoon members have the option to used mobile mesh devices along with their legacy voice assets. This method may provide greater flexibility and a wider range of communication opportunities. The mesh network is extended by multiple network nodes used throughout the battlespace. Therefore wherever a DO unit moves, their RF voice

communications can move across the mesh network. The authors believe this may be one way to bridge current legacy equipment along with emerging mesh technology. Once mesh technology matures then more traditional communications such as VHF could be phased out over time. Until this occurs, this blend of old and new technology may help bridge changing technologies.

Advantages:

- DO platoon can now use the latest mesh technology in conjunction with their legacy radio assets. Each mesh device extends the coverage of the network.
- DO squad members have continuous PLI information as well as other mesh users.
- Redundancy of vital communications is achieved. If mesh communications are lost between squads then legacy radio systems can be used.
- Clients/Units can run mesh software application and Desktop communicator simultaneously on their existing computer assets. Multiple uses of limited resources are achieved.

Disadvantages:

- Mesh devices are LOS communications. If LOS is lost then communications are lost. Therefore terrain is the largest challenge for mesh devices. Legacy radio systems have more graceful degradation of signal and work better in NLOS conditions.
- Complicated network. Required more training of communicators to trouble shoot network problems.
- Wave software currently not designed to specifically incorporate mesh technology. The authors had to manipulate the systems to communicate as needed.
- ITT Mesh does not support multicast.

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V. CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

A. CONCLUSION

The purpose of this research was to examine how to better utilize legacy ground radio assets within an ever growing tactical IP network infrastructure. This research points out the tactical network is growing and reaching those entities that previously lacked connectivity and access. This trend is only likely to continue. For DO this means greater access to network resources.

DO present several communication challenges. Some of which require new technologies and the rethinking of how older technologies are employed. DO units may have to operate independently and may rely on several entities outside traditional organizational structures for fires, intelligence and logistical support. If this is the case, then the Marine Corps should integrate proven communications equipment with technology that can integrate those assets into a common tactical IP network. This research investigates and demonstrates this can be accomplished.

The authors believe traditional tactical voice communication should and will continue to dominant information flow on the battlefield. This is extremely important for DO since contact with the enemy may be most imminent and support from higher may have time restrictions. By bridging radio communications across our tactical internet, DO units will benefit the most since multiple entities can monitor traffic and communicate as needed from several different physical locations on the

network. Additionally more efficient use of limited computer assets or other IP based devices could be used to communicate to DO units.

The experiments conducted at Camp Roberts simulated how such a network would work across various mediums. Initial tests demonstrated mesh technologies across varied terrain and dissimilar networks. The use of near space balloons and IEEE 802.16 technology investigated some long-haul communications opportunities for DO.

The thrust of this thesis focused on bridging legacy radio assets, such as PRC-117F, PRC-148 and PRC-119F across tactical data networks. Experiments included the use of Twisted Pair WAVE technology and the JPS NXU2-A which enabled multiple users to communicate via laptop computers, CISCO IP phones or personal digital assistants (PDAs) to military tactical radios in the field. In some cases distances exceeded 100 miles while not restricting user’s mobility in the field. The uses of IEEE 802.16, IEEE 802.11A and mesh technology were used to facilitate tactical voice communications thereby demonstrating interoperability between older technology and emerging technology. Highlights of the experiments came when users could communicate freely with their tactical VHF/UHF assets through the network to multiple IP devices located at the TOC in Camp Roberts and over 100 miles to Naval Postgraduate School in Monterey.

B. RECOMMENDATIONS FOR FUTURE RESEARCH

1. Additional Field Study

The research conducted in this thesis is centered on employment by small ground units. There exists extensive application of the above concepts across the spectrum of

joint level command and control. Further research is suggested not only in the enabling technologies but also in the employment of the capabilities that are available. Extending the voice network of a small ground unit across the resources of a joint and coalition force opens the door for a multitude of practical application. This capability could have extensive usefulness for intelligence activities for situational awareness and information gathering. Requests for intelligence gathering can be greatly increased as well with a direct connection to the individual on the ground. Further research is also suggested in enabling fire support missions with this technology. Having every element of a fire mission aware of the immediate coordination from ground unit to executing element could greatly increase time on target as well as the overall safety of the mission.

Furthermore, research opportunities exist to analyze the detailed requirements needed of a tactical IP network to support this type of a network. Multicast implementation, quality of service issues, jitter and latency management, and other network implementation items of study are needed. Policy and procedure mechanisms could also be studied to better implement such a network with connections to a number of different services and organizations.

Outside of DOD, future efforts should be made to establish gateways into civilian network voice/data infrastructures where first responders such as, police, fire-rescue or relief organizations may need to communicate with military units. For example, it may not be unreasonable to assume that military units will need to

integrate with civilian law enforcement in the case of natural disasters or terrorist attacks. The ability to bridge dissimilar networks on the tactical or first-responder level is a real problem. This body of research stayed within the context of DO, but could be applied to those entities that must accomplish similar objectives.

APPENDIX A

A. DO PLATOON SURVEY

Survey Consent Agreement:

Introduction. You are invited to participate in a survey regarding **Distributive Operations**.

Procedures. If I agree to participate in this study, I understand I will be provided with an explanation of the purposes of the research, a description of the procedures to be used, identification of any experimental procedures, and the expected duration of my participation.

Risks and Benefits. I understand that this survey does not involve greater than minimal risk and involves no known reasonably foreseeable risks or hazards greater than those encountered in everyday life. I have also been informed of any benefits to myself or to others that may reasonably be expected as a result of this research.

Compensation. I understand that no tangible reward will be given. I understand that a copy of the research results will be available at the conclusion of the experiment.

Confidentiality & Privacy Act. I understand that all records of this study will be kept confidential and that my privacy will be safeguarded. No information will be publicly accessible which could identify me as a participant, and I will be identified only as a code number on all research forms. I understand that records of my participation will be maintained by NPS for five years, after which they will be destroyed.

Voluntary Nature of the Study. I understand that my participation is strictly voluntary, and if I agree to participate, I am free to withdraw at any time without prejudice.

Points of Contact. I understand that if I have any questions or comments regarding this project upon the completion of my participation, I should contact the JC4I Program Officer, LtCol Pfeiffer USAF at (831)656-3635.

Statement of Consent. I have read and understand the above

information. I have asked all questions and have had my questions answered. I agree to participate in this survey. I will be provided with a copy of this form for my records.

Administrator__________________Respondent__________________

Rank:
Billet:
MOS:
Years of Service:
#Number of Combat Tours/Where:

1. **Communications Radio Operator Experience: (Circle which)**
   - Low/Med/High/Very High
   - Low – Push to Talk
   - Med – Load Fill, Program, Change Batteries
   - High – Build Antennas, Retrans Ops, Data and Voice
   - Very High – Operated different types of platforms (HF, VHF and UHF/SATCOM). Operate mobile platforms and networks.

2. **In your experience or knowledge of Distributed Operations, what factors do you believe limit the success of DO the most? Rank in order the most limited (=1) to least (=5)**
   - ☐ Lack of training in weapons and unit level tactics
   - ☐ Lack of suitable communication assets
   - ☐ Lack of fire support
   - ☐ Lack of suitable Intel
   - ☐ Lack of proper logistic support.

   Please explain:____
   ____
   ____
   ____

3. **How important is intra squad communications i.e. every Marine possess a radio?**
   a. Not important
   b. Somewhat important (some impact on mission success)
   c. Important (key to mission success)
   d. Very Important(mission success depends on it)

   Comments:____
   ____

4. **How many communication assets should a DO squad possess and realistically operate?**
   a. 1-2
   b. 3-4
   c. More than 4

   Comments:

5. **How important is it to have a "data" capability (send and receive digital information) at the platoon level or lower?**
   a. Not important
   b. Somewhat important (some impact on mission success)
   c. Important (key to mission success)
   d. Very Important(mission success depends on it)

   Comments:

6. **Should Marines be equipped with digital devices that show a digital map and position location of its members? If so, who should have this capability?**
   a. Every Marines
   b. Fireteam Leaders
   c. Squad Leaders
   d. Platoon HQ

   Comments:

7. **Should all Marines in a DO platoon be required to install, operate and maintain all radio communication assets in their procession and be required to maintain that type of proficiency much like their weapon system proficiency?**
   a. Yes
   b. No
   c. Only designated Platoon members

   Comments:

8. What types of data capability (information other than voice communications) is important for Distributed Operations?

a. Chat – Short messages back and forth
b. Email – Documents, longer messages
c. Documents – Word or PowerPoint files
d. Video – Real-time or prerecorded

Comments:

9. How important is it to be linked into a larger network with your communication assets? i.e. SIPR/NIPR

a. Not important
b. Somewhat important (some impact on mission success)
c. Important (key to mission success)
d. Very Important(mission success depends on it)

Comments:

10. DO platoon could often operate at the furthest reaches of vital fire/air support. Should every squad/fireteam have the ability to call for fire/CAS?

a. Yes
b. No
c. Don't know

Comments:

11. How challenging is it to learn the current communication suite of assets for the average Marine?

a. Not Difficult
b. Difficult
c. Very Difficult

Comments:

12. What comfort level do you have working with computers (laptops or desktops) and or computer type devices (cell phone, videogames)

a. No experience
b. Some experience (Email, Instant messaging)
c. Good experience (Regular use)
d. Very good experience (Solid understanding of the technology)

Comments:____
____
____
____

13. What kind of information do you want "pushed" to you on a regular basis during operations? Please rank in order of importance (1 = most, 6 = least)

- ☐ Latest enemy situation report
- ☐ Latest friendly situation report
- ☐ Position location of unit member's location
- ☐ Location of air craft on station
- ☐ Logistic supply report
- ☐ Status of fire support

14. Considering the heavy reliance of high power communication assets, do you believe DO is limited or constrained by the use of vehicle communications?

a. YES
b. NO
c. Don't know

15. What other factors not covered by this survey, impact you ability to conduct distributive operations?

Comments:____
____
____
____

B. SURVEY RESULTS

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Thursday, October 19, 2006

Results Summary

Show All Pages and Questions | Export... | View Detail >>

Filter Results
To analyze a subset of your data, you can create one or more filters.

Add Filter... **Total:** 34
Visible: 34

Share Results
Your results can be shared with others, without giving access to your account.

Configure... **Status:** Enabled
Reports: Summary and Detail

1. Introduction

1. By clicking on the "Proceed" button, I am acknowledging that I have read and understand this information and that I agree to voluntarily participate in this online survey. I also understand that I may discontinue at any time simply by exiting this website

	Response Percent	Response Total
Yes - Proceed	**100%**	**34**
No -	0%	0
Total Respondents		**34**
(skipped this question)		0

2. Begin the Survey!

2. What is your Rank?

	Response Percent	Response Total
Pvt	2.9%	1
PFC	**38.2%**	**13**
Lcpl	**38.2%**	**13**
Cpl	5.9%	2
Sgt	8.8%	3
SSgt	2.9%	1
1st/2nd Lt.	2.9%	1

Total Respondents	**34**
(skipped this question)	0

3. What is your Billet?

	Response Percent	Response Total
Riflemen	**26.5%**	**9**
Grenadeer	8.8%	3
SAW Gunner	**26.5%**	**9**
Fireteam Leader/JFO	11.8%	4
Squad Leader/JFO	8.8%	3
Platoon Sgt/JTAC	2.9%	1
Platoon Cmdr/JTAC	2.9%	1
View Other (please specify)	20.6%	7
Total Respondents		**34**
(skipped this question)		0

4. What is your MOS?

View **Total Respondents**	**34**
(skipped this question)	0

5. Years of Service:

View **Total Respondents**	**33**
(skipped this question)	1

6. Number of Combat Tours (If applicable):

View **Total Respondents**	**31**
(skipped this question)	3

7. Communications Radio Operator Experience: Low-Med-High-Very High	Response Percent	Response Total
• Low – Push to Talk	11.8%	4
• Med – Load Fill, Program, Change Batteries	**73.5%**	**25**
• High – Build Antennas, Retrans Ops, Data & Voice platforms and networks.	2.9%	1
• Very High – Operated different types of platforms (HF, VHF and UHF/ SATCOM). Operate mobile comm systems and networks.	11.8%	4
	Total Respondents	**34**
	(skipped this question)	**0**

8. In your experience or knowledge of Distributed Operations, what factors do you believe limit the success of DO the most? Rank in order from high to low. (5 Highest - 1 Lowest)

	Five	Four	Three	Two	One	Response Average
a. Lack of training in weapons and unit level tactics	25% (8)	12% (4)	19% (6)	16% (5)	**28% (9)**	**3.09**
b. Lack of suitable communication assets	**45% (15)**	9% (3)	24% (8)	12% (4)	9% (3)	**2.30**
c. Lack of fire support	6% (2)	13% (4)	16% (5)	**35% (11)**	29% (9)	**3.68**
d. Lack of suitable Intel	0% (0)	**31% (10)**	25% (8)	28% (9)	16% (5)	**3.28**
e. Lack of proper logistic support.	27% (9)	**30% (10)**	15% (5)	9% (3)	18% (6)	**2.61**
					Total Respondents	**34**
					(skipped this question)	**0**

9. How important is intra squad communications i.e. every Marine possess a radio?	Response Percent	Response Total
a. Not important	5.9%	2
b. Somewhat important (some impact on mission success)	20.6%	7
c. Important (key to mission success)	50%	17
d. Very Important(mission success depends on it)	26.5%	9
View **Comments**	**55.9%**	**19**
	Total Respondents	**34**
	(skipped this question)	**0**

10. How many communication assets should a DO squad possess and realistically operate?	Response Percent	Response Total
a. 1-2	44.1%	15
b. 3-4	47.1%	16
c. More than 4	8.8%	3
View **Comments**	**55.9%**	**19**
	Total Respondents	**34**
	(skipped this question)	**0**

11. How important is it to have a "data" capability (send and receive digital information) at the platoon level or lower?	Response Percent	Response Total
a. Not important	5.9%	2
b. Somewhat important (some impact on mission success)	**50%**	**17**
c. Important (key to mission success)	32.4%	11
d. Very Important(mission success depends on it)	11.8%	4
View Comments	38.2%	13
	Total Respondents	**34**
	(skipped this question)	**0**

12. Should Marines be equipped with digital devices that show a digital map and position location of its members? If so, who should have this capability?	Response Percent	Response Total
a. Every Marines	14.7%	5
b. Fireteam Leaders	29.4%	10
c. Squad Leaders	44.1%	15
d. Platoon HQ	23.5%	8
View **Comments**	**61.8%**	**21**
	Total Respondents	**34**
	(skipped this question)	**0**

13. Should all Marines in a DO platoon be required to install, operate and maintain all radio communication assets in their procession and be required to maintain that type of proficiency much like their weapon system proficiency?

	Response Percent	Response Total
a. Yes	55.9%	19
b. No	2.9%	1
c. Only designated Platoon members	41.2%	14
View **Comments**	**61.8%**	**21**
Total Respondents		**34**
(skipped this question)		**0**

14. What types of data capability (information other than voice communications) is important for Distributed Operations?

	Response Percent	Response Total
a. Chat – Short messages back and forth	44.1%	15
b. Email – Documents, longer messages	11.8%	4
c. Documents – Word or PowerPoint files	11.8%	4
d. Video – Real-time or prerecorded	**58.8%**	**20**
View Comments	50%	17
Total Respondents		**34**
(skipped this question)		**0**

15. How important is it to be linked into a larger network with your communication assets? i.e. SIPR/NIPR

	Response Percent	Response Total
a. Not important	27.3%	6
b. Somewhat important (some impact on mission success)	**45.5%**	**10**
c. Important (key to mission success)	4.5%	1
d. Very Important(mission success depends on it)	18.2%	4
View Comments	40.9%	9
Total Respondents		**22**
(skipped this question)		**12**

16. DO platoon could often operate at the furthest reaches of vital fire/air support. Should every squad/fireteam have the ability to call for fire/CAS?

	Response Percent	Response Total
a. Yes	**97%**	**32**
b. No	0%	0
c. Don't know	3%	1
View Comments	57.6%	19
Total Respondents		**33**
(skipped this question)		1

17. How challenging is it to learn the current communication suite of assets for the average Marine?

	Response Percent	Response Total
a. Not Difficult	44.1%	15
b. Difficult	50%	17
c. Very Difficult	5.9%	2
View **Comments**	**55.9%**	**19**
Total Respondents		**34**
(skipped this question)		0

18. What comfort level do you have working with computers (laptops or desktops) and or computer type devices (cell phone, videogames)

	Response Percent	Response Total
a. No experience	0%	0
b. Some experience (Email, Instant messaging)	20.6%	7
c. Good experience (Regular use)	**61.8%**	**21**
d. Very good experience (Solid understanding of the technology)	17.6%	6
View Comments	32.4%	11
Total Respondents		**34**
(skipped this question)		0

19. What kind of information do you want "pushed" to you on a regular basis during operations? Please rank in order of importance (6 = Most, 1 = Least)

	Six	Five	Four	Three	Two	One	Response Average
Latest enemy situation report	**71% (24)**	9% (3)	9% (3)	9% (3)	0% (0)	3% (1)	**1.68**
Latest friendly situation report	0% (0)	**50% (17)**	21% (7)	6% (2)	18% (6)	6% (2)	**3.09**
Position location of unit member's location	15% (5)	21% (7)	**35% (12)**	12% (4)	12% (4)	6% (2)	**3.03**
Location of aircraft on station	3% (1)	9% (3)	9% (3)	21% (7)	26% (9)	**32% (11)**	**4.56**
Logistics supply report	9% (3)	3% (1)	3% (1)	26% (9)	12% (4)	**47% (16)**	**4.71**
Status of fire support	0% (0)	9% (3)	25% (8)	28% (9)	**31% (10)**	6% (2)	**4.00**
						Total Respondents	**34**
						(skipped this question)	**0**

20. Considering the heavy reliance of high power communication assets, do you believe DO is limited or constrained by the use of vehicle communications?

	Response Percent	Response Total
a. YES	20.6%	7
b. NO	**41.2%**	**14**
c. Don't know	38.2%	13
Total Respondents		**34**
(skipped this question)		**0**

21. What other factors not covered by this survey, impact your ability to conduct distributive operations?

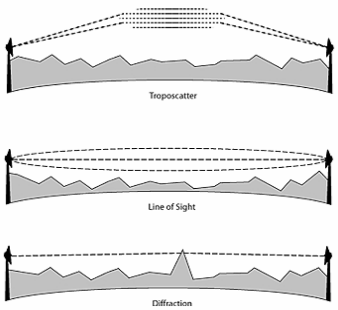
View **Total Respondents**	**17**
(skipped this question)	**17**

APPENDIX B

A. SPEED PROPAGATION MODE

Propagation Mode

PTP identifies troposcatter, LOS, or diffraction as the dominant mode for a signal propagation path. The figure displays the geometry of each type of propagation mode described below:



Troposcatter - This mode is employed beyond LOS, considering loss due to the common scatter volume in the earth troposphere.

Line of Sight - This mode is employed when no intervening terrain obstructs the signal path between the transmitter and the receiver.

Diffraction - This mode is employed when the transmitter and receiver are blocked by terrain. Diffraction mode takes into account the loss due to knife edges formed by natural obstacles such as a mountain ridge and rough terrain.

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APPENDIX C

A. WAVE MANAGEMENT AND SERVER AND NXU CONFIGURATION

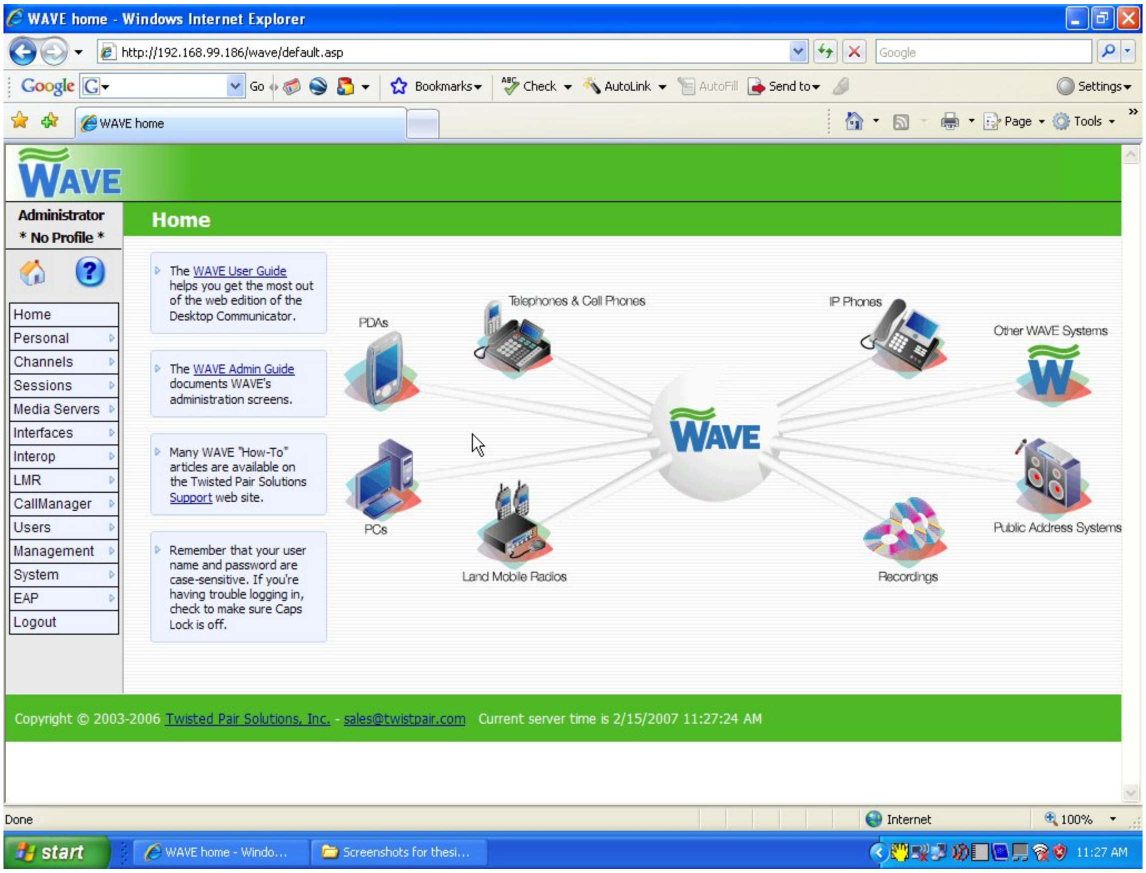

Figure 45. Wave Management Server

Figure 45 depicts the home page for the WAVE Management server. The menu options for configuring the server are located to the left of the page. Access to configuration items on the Media Server is also available from this GUI. The WAVE application operates by licensed options and access to the different capabilities is based on having a validated license file on the server for purchased software options. The management menu options give access to the license file and shows the available licenses loaded on the machine.

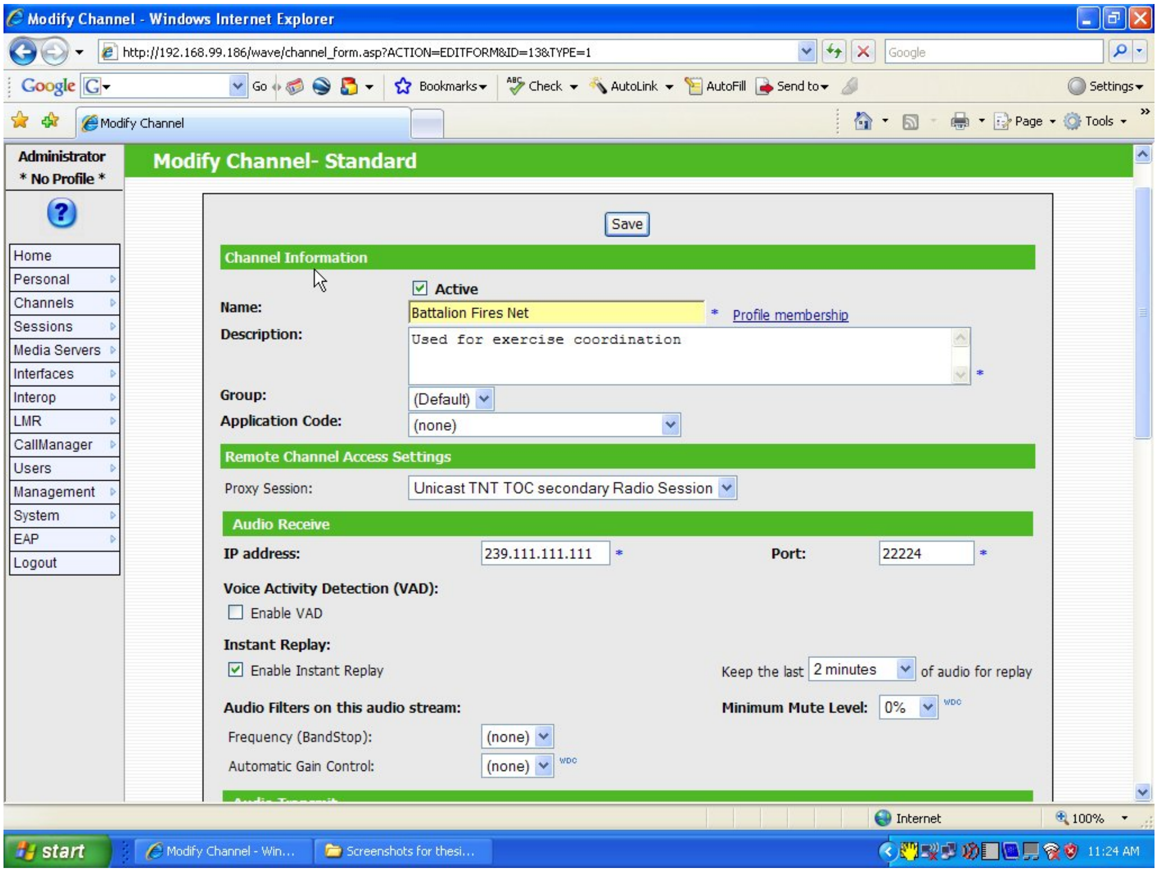

Figure 46. WAVE Channel Configuration

Figure 46 depicts the channel configuration page. Each channel corresponds to a specific voice network. In this case, the Battalion Fires Net is configured with a multicast address of 239.111.111.111 using port 22224. The instant replay option allows the WAVE Desktop Communicator user to replay the last two minutes of a voice transmission. The Proxy Session is a configuration option which allows the channel to operate as unicast rather than multicast. This option was used during our research with a Mesh architecture where the wireless networking cards used did not support multicast. Using the Proxy Session allowed the WAVE Channels to operate seamlessly over these unicast networks.

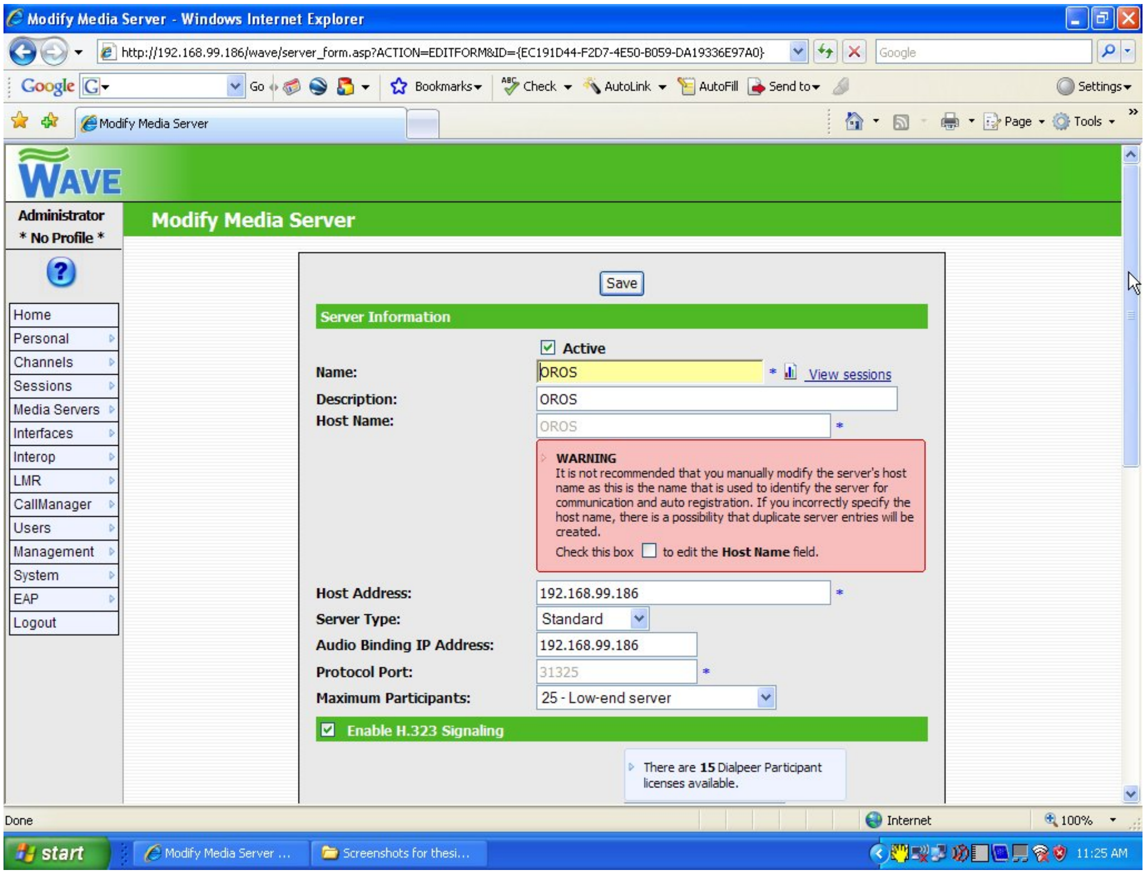

Figure 47. WAVE Media Server Configuration

Figure 47 depicts the configuration page for the WAVE Media Server. In our research application the Media Server software was loaded on the same computer as the WAVE Management Server. The Media Server handles the mixing of audio streams and interfacing for the different channels or sessions assigned to those audio streams.

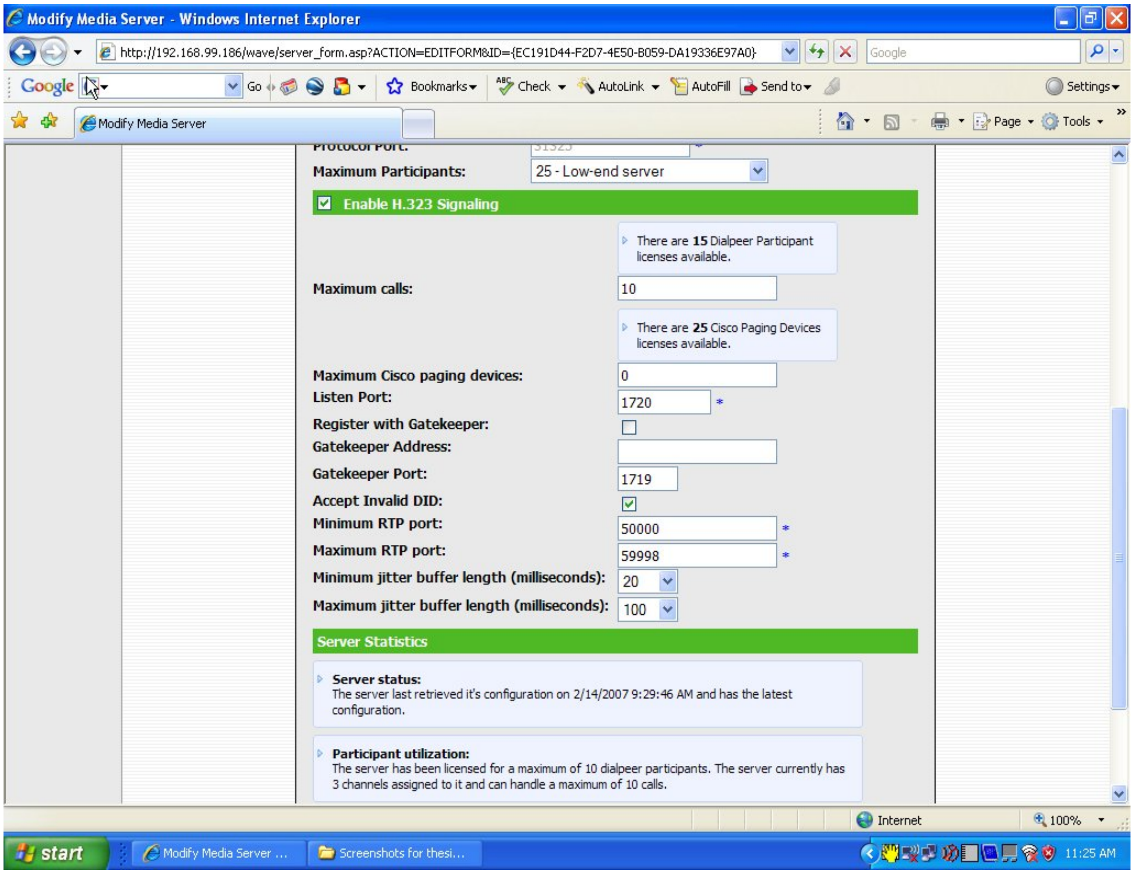

Figure 48. Wave Media Server Configuration Continued

Figure 48 is the continuation of the Media server screen. The screenshot shows there are 10 users allowed access to the server at any given time. This number can be raised or lowered by the administrator based on the number of licenses available and the amount of bandwidth available on the network.

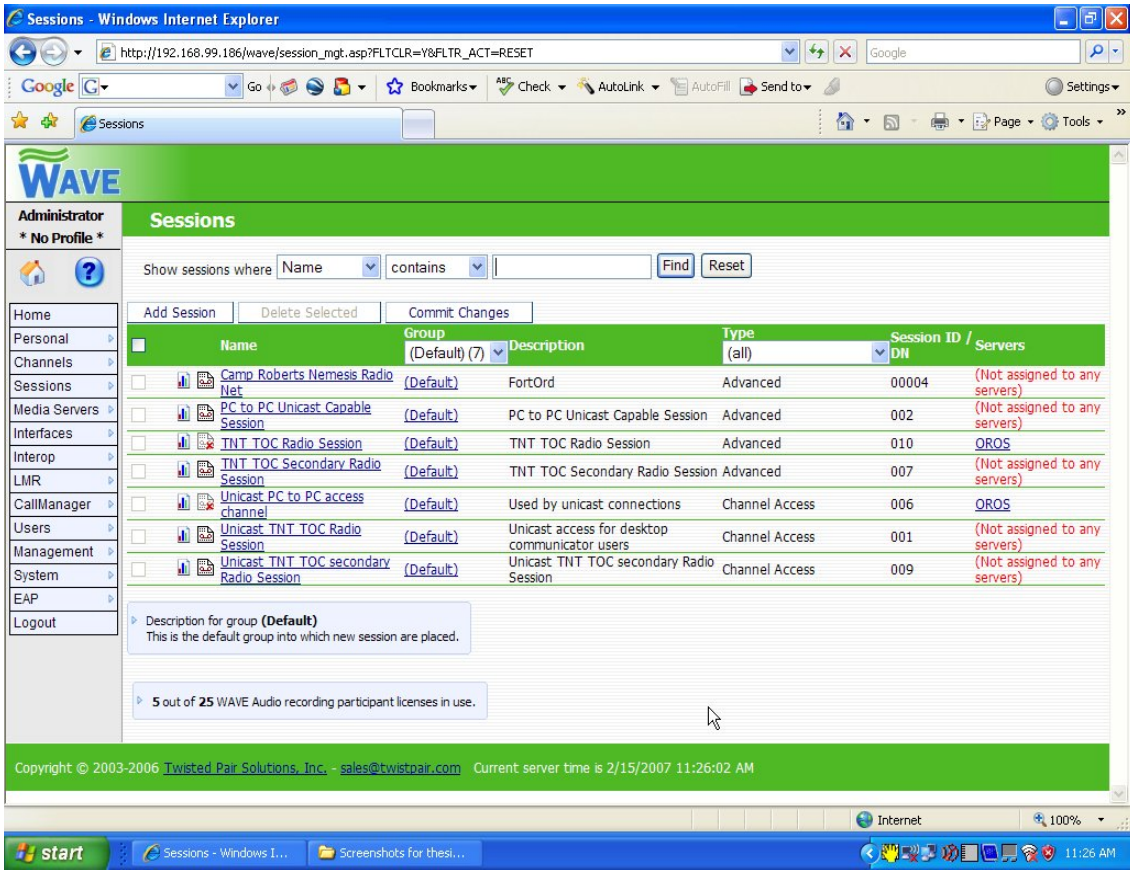

Figure 49. WAVE Session Configuration

Figure 49 shows the session configuration screen. Each session can be configured to give users access to different channels or VOIP devices. Each session can be configured for access by different users as determined by the administrator.

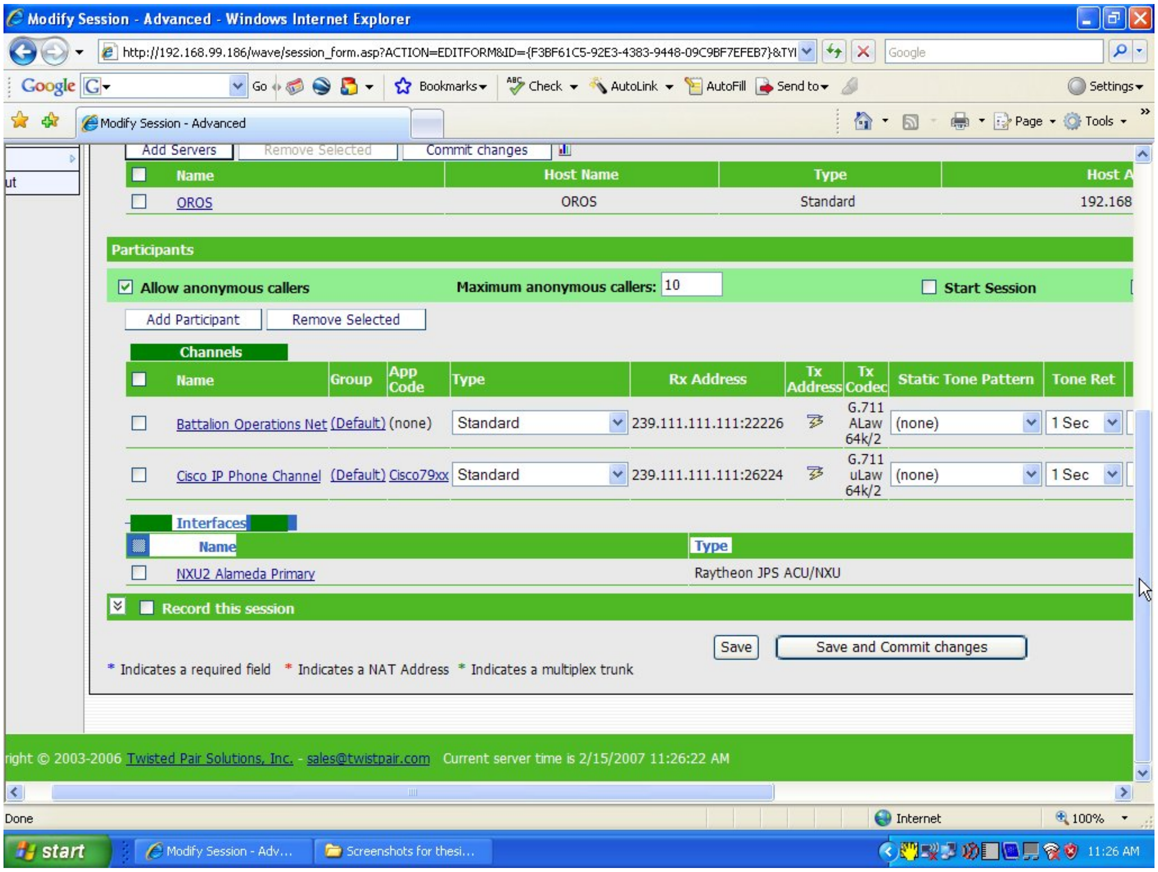

Figure 50. WAVE Session Configuration Continued

Figure 50 shows a session with two channels assigned to it. The Battalion Operations Radio Net and the Cisco IP Phone channels are depicted. The NXU-2A is also shown as an interface allowing the audio from the NXU-2A to be accessed by this session.

B. NXU CONFIGURATION -

Figure 51. NXU-2A Configuration Utility

Figure 51 depicts the web based configuration interface for the NXU-2A. The VOIP port specified is the port used by the WAVE Server for interfacing the NXU-2A. The 13Kbps vocoder was chosen based not only for minimal bandwidth usage but also as the setting recommended for the WAVE server while interfacing the NXU-2A. The VMR setting is required for certain tactical radios due to their being no COR circuit used to initiate a key. VMR is a voice activated setting that opens the circuit once an audible voice signal is detected from the radio by the NXU-2A. There are also potentiometer settings on the back of the NXU-2A that allow the user to change input levels of the audio signal coming from the radio to the NXU-2a.

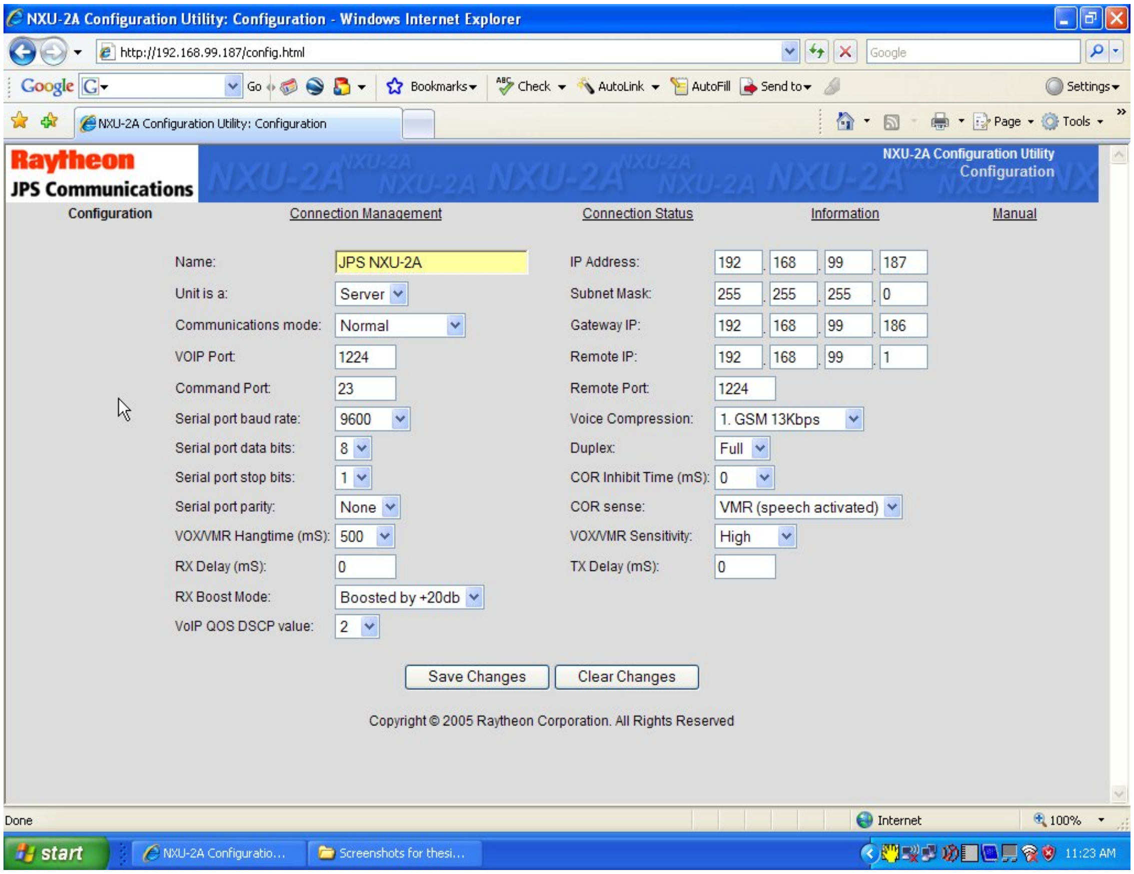

Figure 52. WAVE Configuration Utility Continued

Figure 52 depicts the web based utility page of the NXU-2A that is used for inputting settings. The IP address is statically assigned for the NXU-2A with the remote IP address referring to the WAVE Media Server. The remote port is the voice port used by the WAVE Media server in this application. The Rx Boost Mode was used with the AN/PRC-117 and the AN/PRC-119 to allow for higher audio levels over the network. The unit must be set up as a server when connecting to a WAVE Media server.

APPENDIX D

A. SOLAR WINDS BANDWITH MEASURMENTS

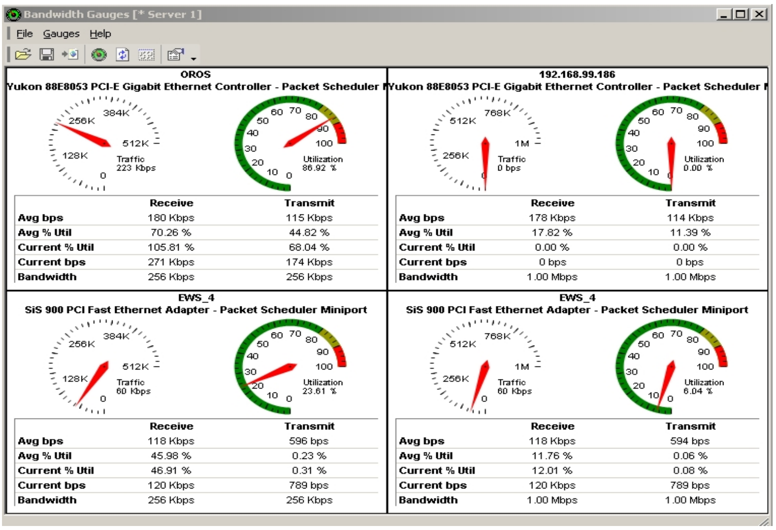

Figure 53. Unencrypted WAVE Server & Client Bandwidth Measurements

Figure 54. 256 Bit AES Encrypted WAVE Server & Client Bandwidth Measurements

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